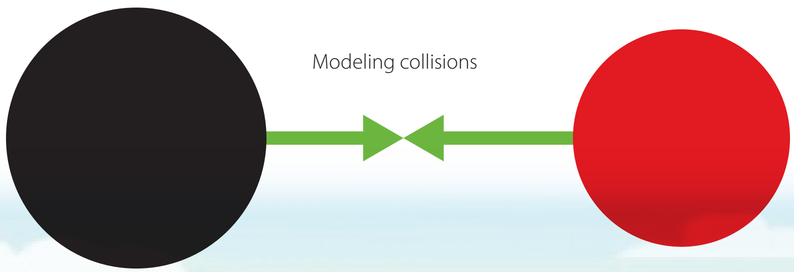
Contact Forces:

Why do things sometimes get damaged when they hit each other?

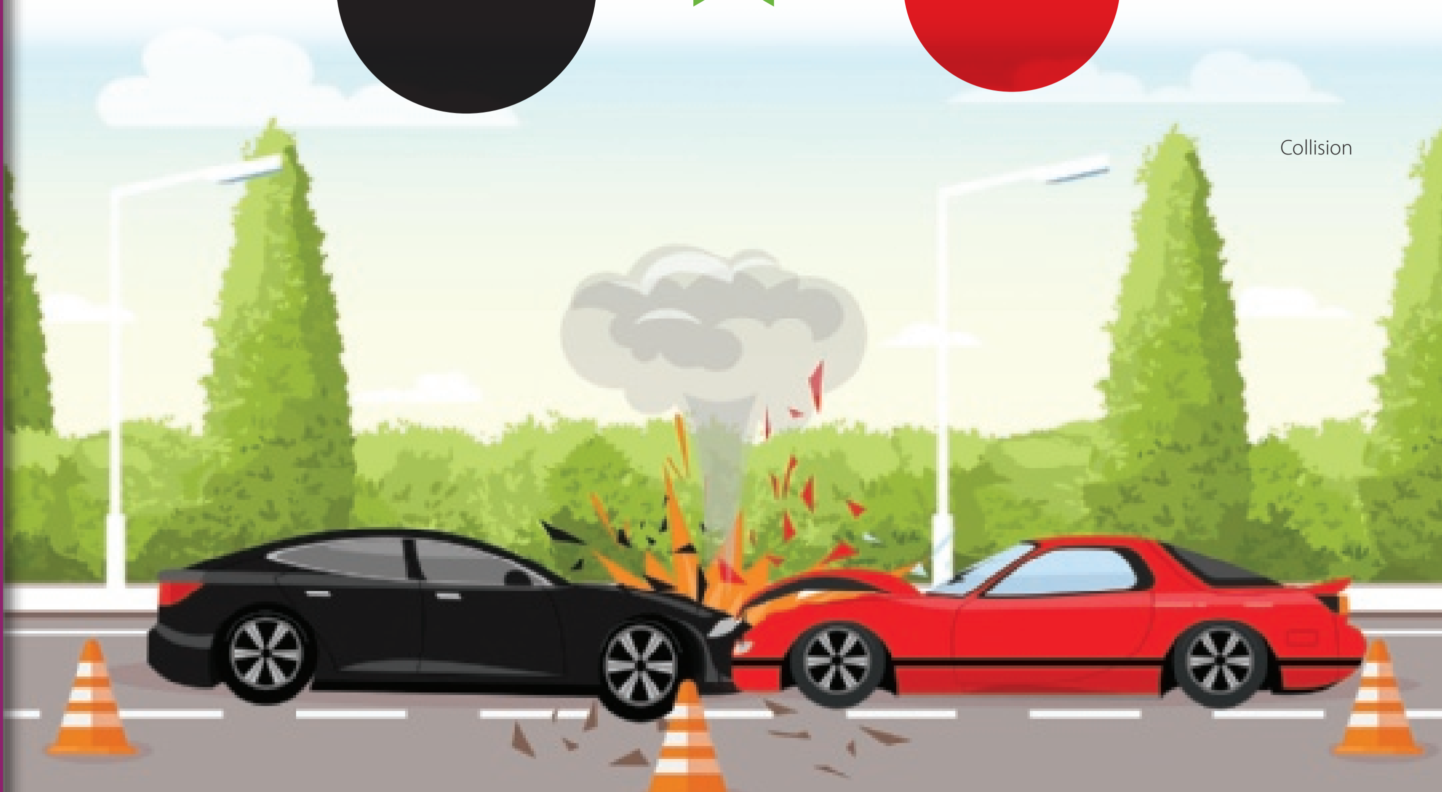
Science Literacy

Teacher Guide

Modeling collisions



Collision



GRADE 8 Core Knowledge Science®

Core Knowledge®

This unit is a modified version of a unit that has earned the NGSS Design Badge. The sole instructional modification is the addition of Core Knowledge Science Literacy content. The modification has not been reviewed.

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Teacher Guide

Core Knowledge®

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BEFORE YOU BEGIN

Before introducing the unit, please become fully acquainted with the program instructional model and classroom routines by reading the online resource **Teacher Handbook: Overview of the Core Knowledge Middle School Science Program**.

Online Resources	Use this link to download the **CKSci Online Resources Guide** for this unit, which includes specific links to: • the unit's comprehensive materials list • a full unit pacing snapshot • lesson guidance slides • all other recommended resources. **www.coreknowledge.org/cksci-online-resources**
Student Work Pages	All student handouts and exercise pages are included in the consumable Student Work Pages book so that there is no need to print copies of these resources.
Student Books	All student handouts and exercise pages are included in the consumable Student Work Pages book so that there is no need to print copies of these resources. Students also will use the Student Procedure Guide and the Science Literacy Student Reader throughout the unit.

UNIT OVERVIEW

Why do things sometimes get damaged when they hit each other?

This unit on contact forces begins as students consider situations in which they have seen their phones break. They contrast these situations with others where something else collided with another object and either did break or, surprisingly, did not. Attempting to identify the factors that contribute to damage occurring in some collisions and not others, as well as trying to explain what is happening during the collision that causes one type of result versus another, sparks a series of questions and ideas for investigations around the question why do things sometimes get damaged when they hit each other? This drives the work for the first two parts of the unit.

In the first part of the unit, students make general observations about what happens to objects during collisions and quickly move to analyzing data that show that objects deform when forces are applied. This leads them to

- plan and carry out investigations and analyze and interpret data to figure out that all solid objects behave elastically up to a point and that the forces between objects in a collision are always equal in size and opposite in direction.
- develop and use free body diagram models to represent the changes in the relative strength of forces on different objects in a collision.
- create and use mathematical models to determine how changes in the mass and speed of an object affect the amount of kinetic energy that object has.
- develop and use system models to support explanations for how contact forces, including friction and air resistance, cause energy to be transferred from one part of the system to another before, during, and after a collision.

In the second part of the unit students design solutions to protect an object of their choice in a collision. They gather design input from stakeholders to refine the criteria and constraints for their design solution, and the class works together to carry out a series of investigations to answer the questions they have about optimizing their design solutions. This leads them to

- plan and carry out investigations to determine which cushioning materials reduce peak forces the most in a collision.
- develop macroscopic models of small and microscopic structures of these materials and use these to generate data about how space to deform, contact time in a collision, and peak forces in a collision are related.
- carry out investigations and analyze data about how the shape and size of cushioning materials affect force distribution in a cushioning structure.

- identify trade-offs, analyze and critique design solutions, and optimize design solutions using evidence from these investigations to solve different design problems for different stakeholders and different contexts.

The final part of the unit re-anchors around a related question and a design problem to figure out what kinds of solutions we can design to protect fragile things from breaking.

Focal Disciplinary Core Ideas (DCIs): PS2.A; PS3.A; ETS1.B; EST1.C; LS1.D

Focal Science and Engineering Practices (SEPs): Planning and Carrying Out Investigations; Analyzing and Interpreting Data; Constructing Explanations and Designing Solutions; Engaging in Argument from Evidence

Focal Crosscutting Concepts (CCCs): Systems and System Models; Stability and Change; Matter and Energy; Structure and Function

Building Toward NGSS Performance Expectations

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

MS-PS2-2: Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

MS-PS3-1: Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.

MS-LS1-8: Gather and synthesize information that sensory receptors respond to stimuli by sending messages to the brain for immediate behavior or storage as memories.

MS-ETS1-2: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

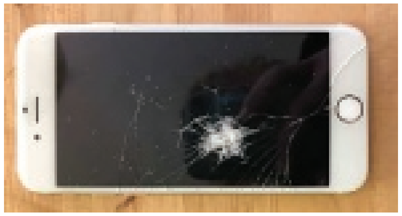
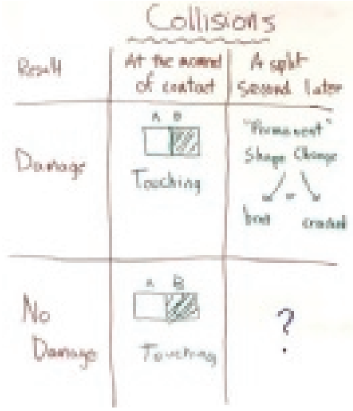
MS-ETS1-3: Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

UNIT STORYLINE

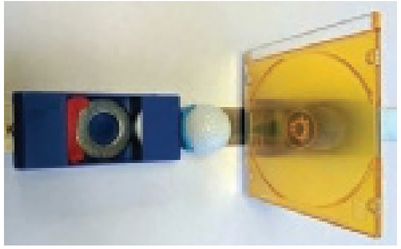
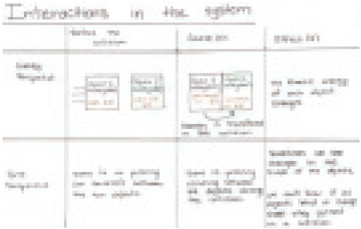
How students will engage with each of the phenomena

HANDS-ON/ LAB ACTIVITIES	VIDEOS OR IMAGES	DATA SETS	READINGS	COMPUTER INTERACTIVES

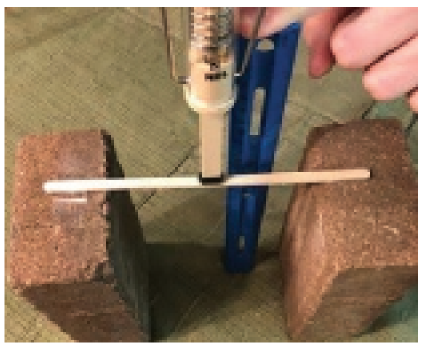
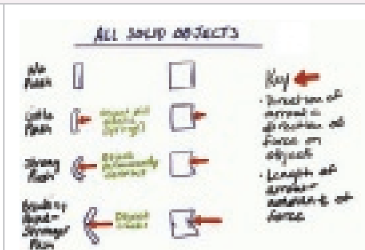
Why do things sometimes get damaged when they hit each other?

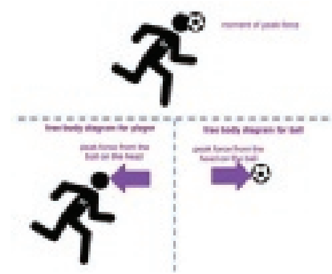
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 1 **3 days** **What happens when two things hit each other?** Anchoring Phenomenon	 *Millions of phones are damaged a year in our country, and many of us have experienced such damage firsthand. We have a lot of experiences where a collision between two objects causes damage and also experiences where it surprisingly does not.*	We model what we think might happen at the moment of impact and a split second after a collision where something breaks and a collision where something doesn't break. We consider some of the factors that could have made a difference in the outcomes of these collisions. This motivates us to create a Driving Question Board (DQB) and brainstorm possible investigations we could do in order to answer our questions. We figure out: • In a collision between two objects, the objects have to come into contact; sometimes something is damaged, but not always. • Different factors and variables may cause objects to be damaged or not damaged in a collision.	

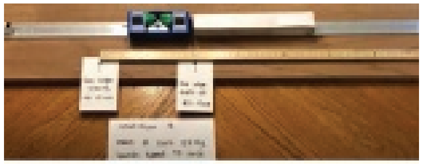
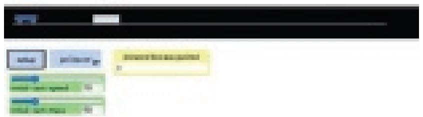
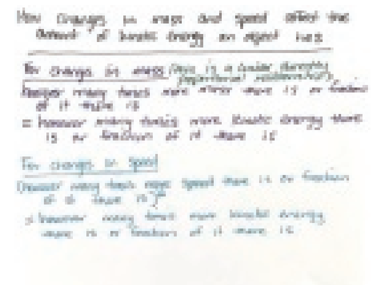
⇩ **Navigation to Next Lesson:** We have a lot of questions about what happens during a collision, so we are wondering if we can look more closely at what happens when different kinds of things collide.

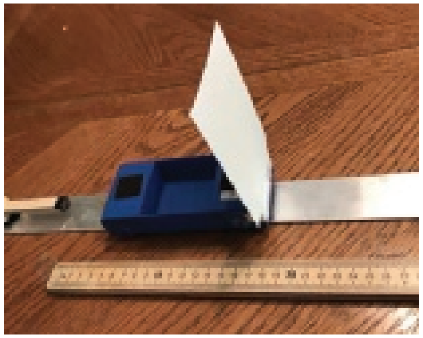
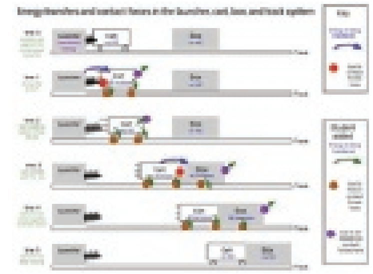
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 2 **2 days** **What causes changes in the motion and shape of colliding objects?** Investigation	 *In collisions between different objects like balls, CD cases, rice noodles, wooden stirrers, crackers, and carts with metal hoops, rubber stoppers, and clay on them, the shape of the objects and/or their motion changes.*	We explore colliding objects and record observations about changes in their motion and shape. We analyze slow-motion videos of some of these collisions. We develop a model to represent what we know about energy transfer and forces occurring in collisions when we see changes in motion of objects, shape of objects, or damage to objects. We figure out: • A collision can cause the objects involved to change motion and/or change shape. • Energy transfer occurs during a collision. • There is a force(s) between objects when they make contact during a collision.	

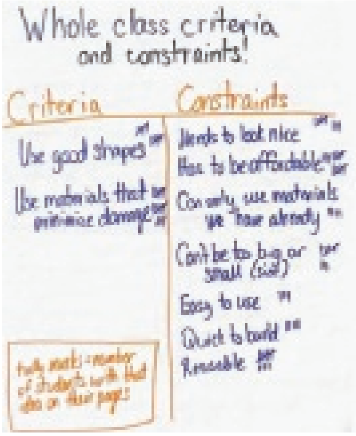
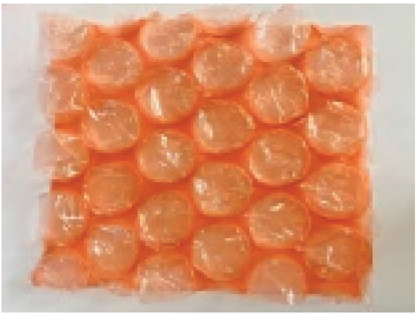
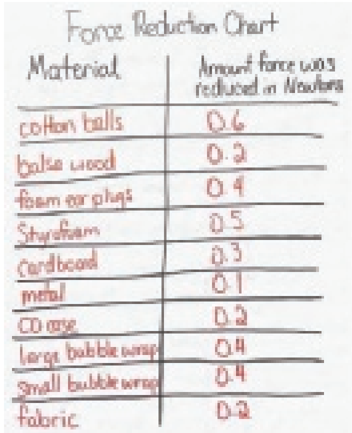
⇩ **Navigation to Next Lesson:** We aren't sure if all objects, especially really rigid ones, change shape during collisions. We need more evidence and think making observations of slow-motion video of rigid objects colliding would help us determine whether this is happening or not.

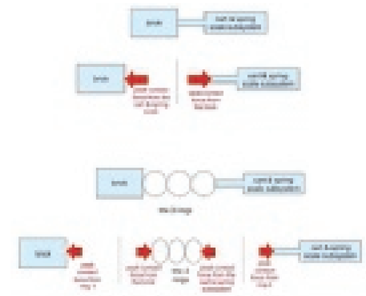
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 3 **1 day** **Do all objects change shape or bend when they are pushed in a collision?** Investigation	 *Cars, golf balls, baseball bats, and baseballs visibly bend and change shape during collisions. A piece of glass and concrete also bend when something else pushes on them.*	We make a claim about whether all solid objects bend or not when pushed during a collision. We analyze slow-motion videos, carry out an investigation with a laser and a mirror, and analyze images from a timelapse concrete joint load testing video. We argue for whether our original claims are supported or refuted by the evidence. We figure out: • All solid objects bend or change shape in a collision and when other contact forces are applied to them.	
⇩ **Navigation to Next Lesson:** Though we figured out that all solid objects deform, we are wondering how much force it takes to deform any solid object, and we started brainstorming ideas about how we could go about investigating this.			
LESSON 4 **2 days** **How much do you have to push on any object to get it to deform (temporarily vs. permanently)?** Investigation	 *All materials have an elastic limit and will deform and return to their original shape in response to an applied force up to a point, beyond which permanent deformation occurs.*	We plan and carry out an investigation to look at the relationship between contact force applied and the amount of deformation that occurs in different materials. We construct graphs of our data and compare them to those from other materials tests. We develop a model to represent the elastic and nonelastic behavior of all solid objects in response to varying amounts of force applied to them. We figure out: • All solid objects deform elastically when force is applied to them, up to a point. • Different objects have a different elastic limit, which is the maximum amount of deformation they can withstand, beyond which they will deform permanently. • Different objects have a different breaking point, which is the maximum amount of deformation they can withstand, beyond which they will crack or split apart. • The type of material, the shape, and the thickness of an object all affect (a) how much it deforms when a force is applied to it, (b) its elastic limit and, (c) its breaking point.	
⇩ **Navigation to Next Lesson:** Though we figured out that all solid objects elastically deform up to a point when forces are applied to them, we aren't really sure which objects are getting pushed on when one object is moving into a stationary object in a collision.			

<table>
<tr><th>Lesson Question</th><th>Phenomena or Design Problem</th><th>What we do and figure out</th><th>How we represent it</th></tr>
<tr>
<td>LESSON 5
2 days
How does changing the mass or speed of a moving object before it collides with another object affect the forces on those objects during the collision?
Investigation</td>
<td>
When one of two objects (fingers or spring scales) is pushed against another of these objects, both objects deform. The peak force registered on a spring scale is the same as the peak force registered on another spring scale when they make contact with each other (either through a static load or during a collision).</td>
<td>We carry out investigations to explore the strength of forces between two objects when they collide. We plan and carry out an investigation about how different speeds and masses of objects affect the amount of peak force on each object. We develop and use a model to represent the relationship between the energy of a moving object and the strength of the peak forces from a collision. We figure out:
• Objects in contact with each other apply equally strong forces on each other in opposite directions.
• Objects that collide apply an equally strong peak force (maximum force) on each other during the collision.
• A free body diagram can help represent the forces on the objects in a collision by considering each object separately.
• Increasing the speed or mass of a moving object increases its kinetic energy (KE).
• The more KE that objects in a system have, the higher the peak forces they can produce in a collision.</td>
<td></td>
</tr>
<tr><td colspan="4">⇩ Navigation to Next Lesson: We have a model that we think can be used to explain why some objects break and others don’t in a collision. We want to test the use of this model on some of our initial questions and try to explain some new and related phenomena.</td></tr>
<tr>
<td>LESSON 6
1 day
What have we figured out about objects interacting in collisions? How can we apply our new learning to answer questions about objects interacting in collisions?
Putting Pieces Together, Problematizing</td>
<td>
Soccer is becoming more and more popular in the United States. And while other soccer-related injuries are happening less frequently, youth soccer players in the United States are experiencing more concussions.</td>
<td>We look back at questions from our Driving Question Board and answer questions we have made progress on during Lesson Set 1. We take an assessment to apply our science ideas to a new context and determine we need to figure out what causes more damage and energy transfer during a collision—increases in mass or increases in speed. We figure out:
• We have made progress on many of our DQB questions.
• We can apply our learning to answer questions about peak forces, damage, and kinetic energy of moving objects in soccer collisions.</td>
<td></td>
</tr>
<tr><td colspan="4">⇩ Navigation to Next Lesson: During our discussion of assessment question 6, we discover we have conflicting ideas of what would cause more damage, increases in the mass or increases in speed of a moving object. We plan to investigate this further in our next lesson.</td></tr>
</table>

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 7 **2 days** **How much does doubling the speed or doubling the mass affect the kinetic energy of an object and the resulting damage that it can do in a collision?** Investigation	  *Changes in the mass and speed of a cart affect how far it pushes a box down a track and the amount of damage it does to a cracker it runs into.*	We carry out an investigation to determine how doubling the speed of an object vs. doubling its mass affects the amount of damage it does in a collision. We analyze data to determine how to quantify the relative change in the kinetic energy of an object. We use a computer simulation to collect additional data on changes in the mass and the speed of a moving object and the amount of kinetic energy. We develop mathematical models of these relationships and use them to predict and explain how this could affect the amount of damage in a collision. We figure out: • In an investigation with multiple independent variables it is important to keep track of which variables are remaining constant and which are changing • The more kinetic energy an object has the more damage it can do in a collision. • The more kinetic energy an object has the more you have to push against the direction of its motion to get it to stop. • The kinetic energy of an object is directly proportional to its mass; the KE of an object is proportional to the square of its speed.	
⇩ **Navigation to Next Lesson:** We have some initial ideas and some specific questions about where the energy is coming and where it is going in our cart-launcher system before and after the cart collided with a cracker or a box.			
LESSON 8 **1 day** **Where did the energy in our launcher system come from, and after the collisions where did it go to?** Investigation	 *A phenomena from the previous lesson: Pulling back a cart against a push-pull spring scale and releasing it results in it launching the cart down a track, the cart running into a box, and the box getting pushed some distance down the track by the cart until both the cart and box stop moving.*	We develop a model to show where energy is transferred between the spring, cart, and box and how contact forces cause this energy transfer. We use this to start brainstorming other places where contact forces may be causing energy transfer in the system. We figure out: • The more force you apply to an object the more that object speeds up. • It takes more force to speed up a more-massive object the same amount as a lower-mass object. • Potential energy can be stored in some systems when you change the shape or arrangement of parts in that system (e.g., a spring). • Contact forces transfer energy between different objects or subsystems within the larger cart-launcher system.	
⇩ **Navigation to Next Lesson:** We have some ideas about other places where contact forces may be causing energy transfer in the system and we want to investigate two of these types of interactions further: sliding along the track surface and moving through the air.			

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 9 **2 days** **How do other contact forces from interactions with the air and the track cause energy transfers in the launcher system?** Investigation	 *An index card on the front of a cart visibly deforms when the cart coasts down the track; it deforms more when a faster headwind is blowing toward it; the cart doesn't travel as far and its direction of motion reverses in a headwind.*	We conduct investigations to gather evidence to explain what other forces affect the kinetic energy of an object before a collision. We develop claims using our evidence and provide and receive feedback with peers to synthesize our ideas. We revise our model to show additional places in the launcher system where energy is transferred and how contact forces cause this energy transfer. We figure out: • Friction is a contact force due to interaction between surfaces in contact and is produced by the bumps (roughness) on surfaces as they push against each other. • Interactions due to friction and air resistance apply contact forces to a moving object that are in a direction that is opposite its motion. • Force interactions due to friction and air resistance transfer energy to the surfaces of the objects that slide over each other; this results in an increase in particle-level kinetic energy (a temperature increase). • Energy can be transferred to and from collisions between objects and particles in the air.	
⇩ **Navigation to Next Lesson:** We know a lot about how damage occurs and we want to explain why some objects break and others don't in collisions.			
LESSON 10 **2 days** **Why do some objects break or not break in a collision?** Putting Pieces Together	 *At each level of organized baseball, there are rules in place about what type of bat and ball can be used to ensure the game play remains competitive, fair, and fun. There are other factors that can impact game play that can't be controlled, such as weather conditions, location of the stadium, and the strength of the players.*	We revisit our collision types from Lesson 1 and explain why some objects were damaged and others weren't in different collisions. We use these ideas to answer questions on the Driving Question Board and take an assessment to apply our new ideas to a new set of collision-related phenomena in the context of baseball. We figure out: • We have made progress on our DQB questions. • We can apply our new learning over mass, speed, peak forces, and energy transfer to explain equipment-related collisions and interactions in baseball.	
⇩ **Navigation to Next Lesson:** We can use our science ideas to answer a lot of questions about what causes damage in a collision, but we still can't explain how certain materials seem to protect against damage better than others in a collision and we have unanswered questions about how these work.			

<table>
<tr><th>Lesson Question</th><th>Phenomena or Design Problem</th><th>What we do and figure out</th><th>How we represent it</th></tr>
<tr>
<td>LESSON 11
2 days
What can we design to better protect objects in a collision?
Anchoring Phenomenon</td>
<td>
All devices designed to protect objects have common criteria and constraints.</td>
<td>We look back at our anchor and discover that some phones were in protective cases when they were damaged. We develop new phone case criteria and constraints and design our own protection device for something we want to protect. We receive feedback on our designs and consider what criteria and constraints all designs need to protect objects. We develop questions about our designs and ideas for investigation. We determine that we need to figure out the best damage-reducing materials. We figure out:
All protection devices have similar criteria and constraints.
Device shape, material, and structure have something to do with protective devices reducing damage to an object.
We need to determine what makes certain materials better at reducing damage than other materials.</td>
<td>
</td>
</tr>
<tr><td colspan="4">⇩ Navigation to Next Lesson: While we figured out that the shared criteria of materials is important, we still need to figure out what makes one material better than another at reducing damage to an object.</td></tr>
<tr>
<td>LESSON 12
2 days
What materials best reduce the peak forces in a collision?
Investigation</td>
<td>
Materials that help to reduce peak force in a collision have similar structures, such as greater deformation abilities and air in their structures.</td>
<td>We conduct an investigation to determine what easily accessible materials reduce peak force in a collision. We compare the structure of the materials and find similarities in their compositions that might affect their function. We also determine that the peak force is reduced equally on both objects, regardless of size. We try to develop a model to explain how the structures of the materials function in a collision that helps to reduce peak forces on the objects we want to protect. We figure out:
Materials that reduce peak force have similar structures, such as air pockets or space for air, and the ability to deform when a contact force is applied; these materials reduce the peak force equally on both objects involved in the collision.</td>
<td>
</td>
</tr>
<tr><td colspan="4">⇩ Navigation to Next Lesson: We know that the protective materials have some similar characteristics, but we are still wondering how those help reduce peak forces when a contact force is applied.</td></tr>
</table>

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 13 **3 days** **How (and why) does the structure of a cushioning material affect the peak forces produced in a collision?** Investigation	 *Cushioning material has repeating patterns of air or space gaps throughout its structure. Repeated chains of open-ring structures put between two colliding objects reduce the peak forces on those objects. Other changes in the arrangement of those structures also affect the forces applied to objects in the system.*	We develop a model to represent how the structures of materials compare in the top four performers for peak force reduction. We use scaled-up versions of these structures to generate data using slow-motion video about the unobservable mechanisms at work in the system. We carry out an investigation to determine how the amount of force applied to different points of a cushioning structure is affected by the shape of that structure. We figure out: • Protective materials tend to have a lot of space (or air) for the solid materials to deform into, which makes these materials relatively easy to deform (with little force applied to them). • The thicker these kinds of materials are, the more they reduce peak forces because this increases the total time the collision takes. • Making a material more densely packed with smaller and smaller spaces does not necessarily reduce peak forces; such increased density may actually have the opposite effect. • The more you can spread the peak forces out over a larger area or over more points of contact, the less force is applied to each point of contact; this can reduce the amount of damage on the material you are trying to protect.	

⇩ **Navigation to Next Lesson:** We started thinking about how what we have figured out could be applied to our protective device design solutions we have been working on as well as how they could be applied to another design problem we encountered earlier (protecting players' heads from concussion in a sports-related context). We are going to try to do this in the work we do across the next two lessons.

<table>
<tr><th>Lesson Question</th><th>Phenomena or Design Problem</th><th>What we do and figure out</th><th>How we represent it</th></tr>
<tr>
<td>LESSON 14
2 days
How can we use our science ideas and other societal wants and needs to refine our designs?
Putting Pieces Together</td>
<td>
When redesigning a device, stakeholder feedback is important to consider. Each change based upon a consideration comes with a trade-off, and those trade-offs have consequences for the usefulness and purpose of the device.</td>
<td>We redesign our protective devices and receive stakeholder feedback. We use the feedback and considerations to inform decisions on primary, secondary and tertiary criteria for materials in a decision matrix. We evaluate the overall scores of the materials and consider the consequences of each change made to the protective devices. We figure out:

Most designs will not meet every criterion and constraint perfectly.
When engaging in an engineering design problem, trade-offs will occur based upon stakeholder feedback.
Some stakeholder considerations will have a higher priority than other considerations.
Every trade-off has consequences.
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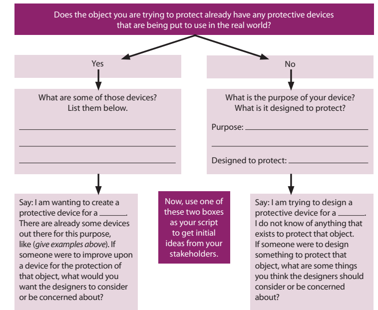
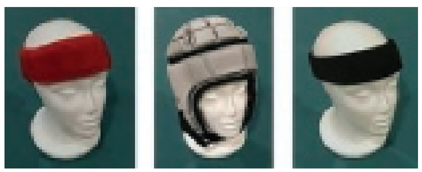
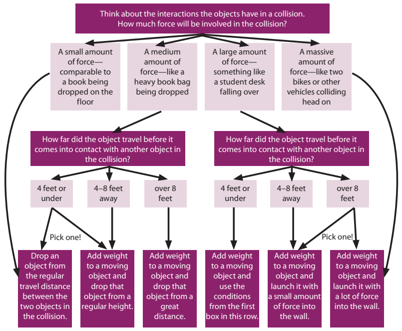
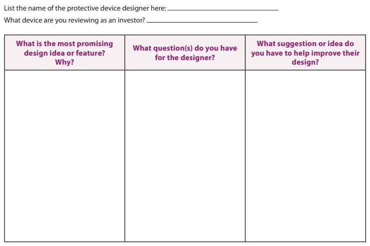
<td>
</td>
</tr>
<tr><td colspan="4">⇩ Navigation to Next Lesson: Now that we have prioritized material choices based upon stakeholder feedback and considerations, we can draft a design brief to share the changes and consequences of those changes with stakeholders.</td></tr>
<tr>
<td>LESSON 15
2 days
How can we use what we figured out to evaluate another engineer's design?
Putting Pieces Together</td>
<td>
Cheerleading is a sport where the participants are at risk of concussions and traditionally haven't worn protective headgear. More recently, headgear from other sports has been used by some cheerleading squads to try to protect their members from injury. An opportunity exists to design a more-customized form of headgear that better meets the needs of this particular sport.</td>
<td>We evaluate other engineers' design solutions to protect cheerleaders from concussions in collisions using the science and engineering ideas we have figured out over the course of the unit. We design our own solution and argue how it takes into consideration the criteria, constraints, and trade-offs considered in the proposed solution. We revisit the DQB to take stock of the questions we have answered.</td>
<td></td>
</tr>
<tr><td colspan="4">⇩ Navigation to Next Lesson: The next lesson is an optional extension for use beyond the formal end of the unit (this lesson) for classrooms that have a strong interest in building, producing, and testing physical prototypes for design solutions students have been refining on paper in the previous lessons.</td></tr>
</table>

<table>
<tr><th>Lesson Question</th><th>Phenomena or Design Problem</th><th>What we do and figure out</th><th>How we represent it</th></tr>
<tr>
<td>LESSON 16
4 days
OPTIONAL How can we market our designs to our potential investors?
Putting Pieces Together</td>
<td>

Investors want a device that is marketable and takes into consideration the needs of stakeholders. Designers need to keep these things in mind when creating a pitch presentation for investors.</td>
<td>In this optional lesson we develop a presentation to share our design with potential investors. We have the option to create a scale prototype and test our design and/or add visual aids to our presentation. We also present our design ideas to investors. We figure out:
• Investors care about the considerations of stakeholders.
• As a designer, information has to be presented in a relevant and engaging way that allows investors to see that all stakeholder considerations have been taken into account.</td>
<td>
List the name of the protective device designer here: ______
What device are you reviewing as an investor? ______
| What is the most promising design idea or feature? Why? | What question(s) do you have for the designer? | What suggestion or idea do you have to help improve their design? |</td>
</tr>
</table>

⇩ **Navigation to Next Lesson:** There is no next lesson.

LESSONS 1–16

33 days total

TEACHER BACKGROUND KNOWLEDGE

Lab Safety Requirements for Science Investigations

It is important to adopt and follow appropriate safety practices within the context of hands-on investigations and demonstrations, whether they are in a traditional science laboratory or in the field. In this way, teachers need to be aware of any school or district safety policies, legal safety standards, and better professional practices that are applicable to hands-on science activities being undertaken.

Science safety practices in laboratories or classrooms require engineering controls and personal protective equipment (e.g., safety goggles, non-latex aprons and gloves, eyewash or shower station, fume hood, and fire extinguishers). Science investigations should always be directly supervised by qualified adults, and safety procedures should be reviewed annually prior to initiating any hands-on activities or demonstrations. Prior to each investigation, students should be reminded of the specific safety procedures that need to be followed. Each lesson within the units includes teacher guidelines for applicable safety procedures for setting up and running any investigations as well as taking down, disposing of, and storing materials.

Prior to the first science investigation of the year, a safety acknowledgement form for students and parents or guardians should be provided and signed. You can access a model safety acknowledgement form for middle school activities. (See the **Online Resources Guide** for links to these items.
www.coreknowledge.org/cksci-online-resources)

Disclaimer: The safety precautions of each activity are based in part on use of the specifically recommended materials and instructions, legal safety standards, and better professional safety practices. Be aware that the selection of alternative materials or procedures for these activities may jeopardize the level of safety and therefore is at the user's own risk.

Please follow these lab safety recommendations for any lesson with an investigation:

1. Wear safety goggles (specifically, indirectly vented chemical splash goggles), a nonlatex apron, and nonlatex gloves during the setup, hands-on investigation, and take down segments of the activity.
2. Immediately wipe up any spilled water and/or granules on the floor, as this is a slip and fall hazard.
3. Follow your *Teacher Guide* for instructions on disposing of waste materials and/or storage of materials.
4. Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
5. Wash your hands with soap and water immediately after completing this activity.
6. Never eat any food items used in a lab activity.
7. Never taste any substance or chemical in the lab.

Specific safety precautions are called out within the lesson using this icon and a callout box.

Where does this unit fall in the Scope and Sequence?

Unit 8.1: Why do things sometimes get damaged when they hit each other? (Collisions Unit) is the first unit in the 8th grade scope and sequence. There are six units designed for 8th grade. This unit directly builds off the disciplinary core ideas (DCIs), crosscutting concepts (CCCs), and science and engineering practices (SEPs) developed in 6th grade units that preceded this one. Those units are

- *Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)*
- *Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit)*

There are three 8th grade units that follow this unit that will build off the DCIs, CCCs, and SEPs developed in this unit. Those units are

- *Unit 8.2: How can a sound make something move? (Sound Unit)*
- *Unit 8.3: How can a magnet move another object without touching it? (Magnets Unit)*
- *Unit 8.4: Why do we see patterns in the sky, and what else is out there that we can't see? (Space Unit)*

What phenomena are the context for this unit?

This unit begins with students considering situations in which they have seen their phones break. They contrast these situations with others where something else collided with another object and either did break or, surprisingly, did not. Attempting to identify the factors that contribute to damage occurring in some collisions and not others, as well as trying to explain what is happening during the collision that causes one type of result versus another, sparks a series of questions and ideas for investigations around the question, why do things sometimes get damaged when they hit each other?

This unit is broken into three lesson sets focusing on force interactions between colliding objects, energy transfer in collisions, and how the structure of materials can mitigate the damage that a collision can cause.

In the first lesson set of the unit students make general observations about what happens to objects during collisions and quickly move to analyzing data that show that objects deform when forces are applied. This leads them to plan and carry out investigations and analyze and interpret data to figure out that all solid objects behave elastically up to a point and that the forces between objects in a collision are always equal in size and opposite in direction. The results of these investigations allow them to develop and use free-body diagram models to represent the changes in the relative strength of forces on different objects in a collision.

In the second lesson set of the unit students create and use mathematical models to determine how changes in the mass and speed of an object affect the amount of kinetic energy that object has. They unite two different perspectives (energy and forces) to develop and use system models to support explanations for how contact forces, including friction and air resistance, cause energy to be transferred from one part of the system to another before, during, and after a collision.

In the third part of the unit students design solutions to protect an object of their choice in a collision. They gather design input from stakeholders to refine the criteria and constraints for their design solution, and the class works together to carry out a series of investigations to answer the questions they have about optimizing their design solutions. This leads them to plan and carry out investigations to determine which cushioning materials reduce peak forces the most in a collision and to develop macroscopic models of small and microscopic structures of these materials. They use these models to generate data about how space to deform, contact time in a collision, and peak forces in a collision are related. And they carry out additional investigations and analyze data about how the shape and size of cushioning materials affect force distribution in a cushioning structure. They use what they figure out from these investigations: identify trade-offs, analyze and critique design solutions, and optimize a design solution to solve different design problems for different stakeholders and different contexts.

This unit builds toward the following NGSS performance expectations (PEs):

Physical Science PEs

- **MS-PS2-1** Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects. [*Clarification Statement*: Examples of practical problems could include the impact of collisions between two cars, between a car and stationary objects, and between a meteor and a space vehicle.] [*Assessment Boundary*: Assessment is limited to vertical or horizontal interactions in one dimension.]
- **MS-PS-2-2** Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object. [*Clarification Statement*: Emphasis is on balanced (Newton's First Law) and unbalanced forces in a system, qualitative comparisons of forces, mass and changes in motion (Newton's Second Law), frame of reference, and specification of units.] [*Assessment Boundary*: Assessment is limited to forces and changes in motion in one dimension and in an inertial reference frame and to change in one variable at a time. Assessment does not include the use of trigonometry.]
- **MS-PS3-1** Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object. [*Clarification Statement*: Emphasis is on descriptive relationships between kinetic energy and mass separately from kinetic energy and speed. Examples could include riding a bicycle at different speeds, rolling different sizes of rocks downhill, and getting hit by a wiffle ball versus a tennis ball.]
- **MS-ETS1-2** Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
- **MS-ETS1-3** Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

The following PE will be developed over three units: *Unit 6.1: Why do we sometimes see different things when looking at the same object? (One-way Mirror Unit)*, *Unit 7.1: How can we make something new that was not there before? (Bath*

Bombs Unit), and *Unit 8.2: How can a sound make something move? (Sound Unit)*. This unit will address only the mechanical inputs that transmit signals to the brain through touch. The other units will address electromagnetic and other mechanical inputs (sound) and chemical inputs as well as the connection to signals processing in the brain. This unit, however, does make an important connection to how those signals are stored as memories and how damage to particular structures (axons on neurons) can cause memory loss in concussions.

- **MS-LS1-8.** Gather and synthesize information that sensory receptors respond to stimuli by sending messages to the brain for ~~immediate behavior or~~ storage as memories. [*Assessment Boundary*: Assessment does not include mechanisms for transmission of this information.]

What are the disciplinary core ideas (DCIs) in the context of the phenomenon?

Disciplinary core ideas are reproduced verbatim from *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. National Research Council; Division of Behavioral and Social Sciences and Education; Board on Science Education; Committee on a Conceptual Framework for New K-12 Science Education Standards. National Academies Press, Washington, DC. This material may be reproduced and used by other parties with this attribution. If the original material is altered in any way, the attribution must state that the material is adapted from the original.)

PS2.A: Forces and Motion

- For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law).
- The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion.
- All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared.

PS3.A: Definitions of Energy

- Motion energy is properly called kinetic energy ; it is proportional to the mass of the moving object and grows with the square of its speed.

ETS1.B: Developing Possible Solutions

- There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. .
- Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors.

ETS1.C: Optimizing the Design Solution

- Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design.

LS1.D: Information Processing

- Each sense receptor responds to different inputs (~~electromagnetic~~, mechanical, chemical), transmitting them as signals that travel along nerve cells to the brain. The signals are then processed in the brain, resulting in ~~immediate behaviors or~~ memories.

Besides the disciplinary core ideas that are part of the foundation boxes for the target PEs in this unit, additional connections to the following DCIs are also developed and used in this unit:

PS3.B: Conservation of Energy and Energy Transfer

- When the kinetic energy of an object changes, there is inevitably some other change in energy at the same time.

PS3.C: Relationship Between Energy and Forces

- When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object.

What DCIs should my students know from earlier units?

Before this unit, students should understand the following ideas from their experiences in *Unit 6.1: Why do we sometimes see different things when looking at the same object? (One-way Mirror Unit)*.

- The brain pieces together the information to tell us what we "see."
- Large groups of cells work together to form tissues or organs that work together to perform particular body functions.

They should also understand the following ideas from their experiences in *Cup Design Unit* and *Storms Unit*:

- Motion energy is properly called kinetic energy (part of PS3.A).

- Temperature is a measure of the average kinetic energy of particles of matter (part of PS3.A).
- Energy is transferred in particle-level collisions within and between gases, solids, and liquids (e.g. through conduction).

What should my students know from earlier grades?

Before middle school students should have done work related to the following performance expectations:

- **K-PS2-1** Plan and conduct an investigation to compare the effects of different strengths or different directions of pushes and pulls on the motion of an object. [*Clarification Statement*: Examples of pushes or pulls could include a string attached to an object being pulled, a person pushing an object, a person stopping a rolling ball, and two objects colliding and pushing on each other.] [*Assessment Boundary*: Assessment is limited to different relative strengths or different directions, but not both at the same time. Assessment does not include non-contact pushes or pulls such as those produced by magnets.]
- **4-PS3-1** Use evidence to construct an explanation relating the speed of an object to the energy of that object. [*Assessment Boundary*: Assessment does not include quantitative measures of changes in the speed of an object or on any precise or quantitative definition of energy.]
- **4-PS3-3** Ask questions and predict outcomes about the changes in energy that occur when objects collide. [*Clarification Statement*: Emphasis is on the changes in the energy due to changes in speed, not on the forces, as objects interact.] [*Assessment Boundary*: Assessment does not include quantitative measurements of energy.]

From this prior work students should understand these pieces of the DCIs from the foundation boxes for the PEs listed above:

- Speed is related to the energy of a moving object.
- Energy transfer occurs in a collision.
- Pushes and pulls can have different strengths and directions.
- Pushes and pulls can change the speed or direction of an object (they can start or stop it).
- When objects touch or collide, they push on one another.
- A bigger push or pull makes things speed up or slow down more quickly.

What are the focal science and engineering practices (SEPs) for this unit?

While this unit engages students in multiple SEPs across the lesson-level performance expectations for all the lessons in the unit, there is one focal practice that this unit targets to support students' development in a learning progression across the 8th grade year for the SEPs:

- Planning and Carrying Out Investigations

In addition, there are three supporting practices that students will utilize over the course of the unit:

- Analyzing and Interpreting Data
- Constructing Explanations and Designing Solutions
- Engaging in Argument from Evidence

This unit is designed to be taught at the start of 8th grade. If it is taught in 6th or 7th grade, be prepared to provide students greater support in the following SEPs. Students will have already developed some elements of these practices in prior units of instruction:

- **Analyzing and Interpreting Data.** This includes graphing bivariate data, looking for lines of best fit, identifying linear vs. nonlinear patterns in the data, and identifying quantitative relationships in it (rates of changes, scale factors of growth). If this unit is taught at an earlier grade level, look at the additional prerequisite ideas identified in the section below: "What are prerequisite math concepts necessary for the unit?"
- **Planning and Carrying Out Investigations.** This unit builds on a series of prior experiences in multiple units with identifying independent, dependent, and controlled variables in investigation designs and determining how data will be collected, how much data are needed to answer the question of the investigation, and how they can be organized as they are collected. Though Lesson 4 briefly reintroduces these ideas, Lesson 5 assumes students are literate in them.
- **Engaging in Argument from Evidence.** When students enter 8th grade and begin their investigations into the phenomenon of this unit, it is assumed they have completed the units in the scope and sequence prior to this unit. In the *Bath Bombs Unit*, students spent multiple lessons developing the scientific practice of engaging in argumentation to support or refute a claim. Over the course of that unit as they figured out the mechanisms (the how or why) of what happens when a new substance is

made from an original substance or substances, they further developed this skill of argumentation to be able to *construct explanations* including the mechanisms as part of the reasoning that a phenomenon occurs. In *Bath Bombs Unit* the class developed an anchor chart as they engaged with these two practices. If you teach this unit in a different order than laid out in the scope and sequence, you may need to spend some time laying the groundwork and supporting students in developing this practice of engaging in argumentation.

- **Constructing Explanations and Designing Solutions.** This units builds on students' prior experiences with designing solutions, particularly related to the role of defining a problem, criteria, and constraints; identifying stakeholders; incorporating test results into redesigns; and considering and justifying tradeoffs as part of a design solution. In prior work students developed a model for a full engineering design process that captures the work that is done across MS-ETS1-1, MS-ETS1-12 MS-ETS1-3, MS-ETS1-4. The work in defining the problem, the criteria and constraints, and stakeholders is reintroduced relatively quickly, therefore, in Lesson 11. The work in considering test results and trade-offs and optimizing the design based on these is also introduced relatively quickly in Lesson 14.

What are the focal crosscutting concepts (CCCs) for this unit?

While this unit engages students in multiple CCCs across the lesson-level performance expectations for all the lessons in the unit, there are four focal CCCs that this unit targets to support students' development in a learning progression for the CCCs across the 8th grade year:

- Systems and system models
- Energy and matter
- Structure and function
- Stability and change

Students will have already developed substantial fluency with two of these focal CCCs in prior units of instruction. These related ideas will be leveraged in this unit:

- **Systems and system models**
  - Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems.
    - The idea of subsystems (or objects) making up parts of larger systems of interacting parts is introduced in Lesson 2, and this lesson and subsequent Lessons (8, 9, 10, 11, 13, 14, 15) refer to this sort of thinking without providing additional support beyond the introduction of free-body diagrams as a type of subsystem model in Lesson 5.
  - Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems.
    - Lesson 2 reintroduces two types of energy that were established in prior units of instruction. One is motion lines or streaks whose length indicates relative changes in the speed of an object and are used to represent changes in the kinetic energy of an object. Another is arced arrows between two objects or subsystems to indicate the direction of energy transfer in the system. Lesson 2 also reintroduces a type of representation for forces applied to objects (thick arrows), whose size indicates the relative strength of force, that was originally introduced in *Storms Unit*.
  - Models are limited in that they only represent certain aspects of the system under study.
    - Lesson 2 introduces two different modeling perspectives (an energy perspective and a forces perspective). Later lessons incrementally unite these perspectives (Lessons 5, 7, 8, 9, and 10). Two subsequent 8th grade units will build off this two-perspective approach to system thinking in physical science-related phenomena: *Unit 8.2: How can a sound make something move? (Sound Unit)* and *Magnets Unit*.
    - Lesson 12 builds on experiences in prior units with developing and using models for producing data and developing and using models of systems whose processes or mechanisms are occurring at a scale that can't be directly observed.
    - Though a general reintroduction to the nature of models is provided in Lesson 1, students are expected to fluently develop models of systems and subsystems, representing different points in time in the system, representing structures at different scales (microscopic and macroscopic), as well as distinguishing between the use of representations for energy transfer and for application of forces to an object.
- **Energy and matter**
  - Within a natural or designed system, the transfer of energy drives the motion and/or cycling of matter.
    - This idea is reintroduced in Lesson 2. Prior work on *Cup Design Unit* established the idea that energy transfer between particle collisions accounts for the flow of thermal energy (heat) through matter.

    - Particle level collisions are a focus of the system models that students develop in Lesson 8 and 9.
  - Energy may take different forms (e.g., energy in fields, thermal energy, energy of motion).
    - Thermal energy was introduced in *Cup Design Unit* and *Storms Unit* as the total kinetic energy of the particles that make up a subsystem. This idea is reintroduced in Lesson 9. Accounting for friction in the system through the lens of macroscopic to microscopic kinetic energy transfer is the focus of this lesson.
    - The idea of stored potential energy is introduced in Lesson 8. It is the first introduction of the idea that the arrangement of parts of a system can store energy in the system. But it does build on a related idea that was introduced in *Homemade Heater Unit* that energy can have different forms in a chemical process and that the changes in the thermal energy of the system must be due to the rearrangement of parts (atoms) in the system (through a chemical process).
  - The transfer of energy can be tracked as energy flows through a designed or natural system.
    - This idea is introduced in Lesson 2 and is reused in Lessons 8 and 9 as students revise a system model to support an argument that energy of the moving objects (the box and the cart) must be transferred to the surroundings.
- **Structure and function**
  - Complex and microscopic structures and systems can be visualized, modeled, and used to describe how their function depends on the relationships among its parts; therefore, complex natural and designed structures/systems can be analyzed to determine how they function.
    - This idea is leveraged in Lesson Set 3 (Lessons 11-15). Students will have encountered this idea in their work in a prior unit of instruction: *Cup Design Unit*.
  - Structures can be designed to serve particular functions by taking into account properties of different materials and how materials can be shaped and used.
    - This idea is leveraged in Lesson Set 3 (Lessons 11-15). Students will have encountered this idea in their work in a prior unit of instruction: *Cup Design Unit*.
- **Stability and change**
  - Small changes in one part of a system might cause large changes in another part.
    - Students have developed this idea in their prior work in *Homemade Heater Unit* through consideration of trade-offs in the design solutions they worked on in that unit. This prior work with trade-offs in physical systems will be leveraged in Lessons 14 and 15 of this unit.
  - Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and processes <u>at different scales</u>, including the atomic scale.
    - Students will have done prior work with this idea in *Storms Unit*, having looked at stability and change related to forces on particles of water. This included:
      - How intermolecular forces between water particles (molecules) can help account for phase changes in water occurring at certain temperatures
      - How balanced and unbalanced forces on water droplets and ice crystals can account for why water falls out of clouds sometimes and not others.
    - Balanced and unbalanced forces will be represented in some of the free-body diagram models students develop in this unit. The underlined portion of the statement above is expanded in this unit to look at forces on and within substructures that make up cushioning materials at a microscopic level that is bigger than the molecular particle level.
    - In lesson 8, students also identify where contact forces are occurring on the surface of macroscopic objects due to microscopic interactions, including both a) collisions with air molecules and b) deformation of small scale grooves and ridges in the rough surfaces of objects sliding against each other due to friction. They use these microscopic force interactions to account for why the objects that were moving in a system (a cart and box) slow down and eventually stop.

Though this is not a focal CCC in the unit, be prepared to provide students greater support in this CCC, which students will have already developed substantial fluency with related to this idea in prior units of instruction:

- **Patterns**
  - Macroscopic patterns are related to the nature of microscopic and atomic-level structure.
    - Students will do a large amount of structure and function thinking at the microscopic level to account for macroscopic properties of cushioning materials in Lessons 12 through 15. This structure and function thinking leverages students' prior work with patterns related to the idea listed above. Students will have modeled zoom-in bubbles to show what is happening to the particles of matter in units *Cup Design Unit*, *Storms Unit*, *Bath Bombs Unit*, and *Homemade Heater Unit*. And they will develop and use cellular- and tissue-level structures (microscopic) to explain life science-related phenomena in *Inside Our Bodies Unit* and *Maple Syrup Unit*. The scale of the structures they are modeling in this unit are larger than particles or cells but still at the microscopic scale.

What are prerequisite math concepts necessary for the unit?

Because this unit is taught using a conceptual approach to describing the relationship among force, mass, and change in motion during collisions, students need only have experience with qualitatively reasoning about direct and inverse relationships (e.g., as force increases, change in motion increases; but as mass increases, change in motion from a given force decreases).

But because the focus of **MS-PS3-1** is on quantitative understanding of the relationship of the kinetic energy of an object to the mass of an object and to the speed of an object, students will need to leverage the following experiences from grade 7 CCS math to use in this unit in Lessons 7 and 10:

- Working with unit rates and ratios is within the 6th and 7th grade Common Core Math Standards. By the beginning of 8th grade, students should be well versed in how to do this calculation. It will be leveraged in Lessons 7 and 10 of this unit when students recognize that the relationship between mass and kinetic energy is directly proportional. Such a relationship is one they have encountered in graphs many times in Common Core mathematics since 6th grade. Recognizing the relationship between speed and kinetic energy as nonlinear will also be straightforward. But describing the change in kinetic energy as being related to the square of the speed of an object will be challenging. Students will have encountered working with squared relationships in 6th grade in finding the surface area of a cube with sides of length *s*, and in 8th grade they will be working with squaring the side lengths of a right triangle in their work with the Pythagorean theorem. Coordinate with your math teachers to determine where your students will be at in their familiarity with thinking about relationships like these.
- Students calculate and use a type of ratio called a scale factor in Lesson 7. Students will have encountered this concept before in math class in one or both of these contexts:
  - **7.G.A.1** Solve problems involving scale drawings of geometric figures, including computing actual lengths and areas from a scale drawing and reproducing a scale drawing at a different scale.
  - **7.RP.A.2** Recognize and represent proportional relationships between quantities.
- There are multiple connections between the work students will be doing in Lesson 7 and the work they will be doing in math class this year (grade 8). These include the following:
  - **8.F.B.5** Describe qualitatively the functional relationship between two quantities by analyzing a graph (e.g., where the function is increasing or decreasing, linear or nonlinear).
  - **8.EE.A.1** Know and apply the properties of integer exponents to generate equivalent numerical expressions.

Because data from investigations are often scattered due to source of error, even when the expected trend in the data is linear, students are introduced to lines of best fit in Lesson 4 in this unit. They reuse this construct in the Lesson 10 assessment. Students do not have to have encountered this idea in previous mathematics instruction. Lesson 4 assumes that this may be the first time students encountered this idea.

What are some common ideas that students might have?

Students may have the following ideas:

- A force is a property of a single object rather than the result of two interacting objects.
- In a single collision, a heavier or faster-moving object would push harder than a lighter, slower object.
- Only moving objects push on stationary objects, but stationary objects do not push back on the moving ones.
- Inanimate objects don't exert forces on objects that make contact with them (e.g., a hand) because they are not living.
- Some (or all) solids are not elastically deformable. Students may have previously encountered a partial definition of a solid that is characterized

as a state of matter that holds its shape (as opposed to a liquid that takes the shape of the bottom part of its container).

Some students may have heard that for any action there is an equal and opposite reaction, but they may not see that this describes what is happening at any point of contact and in any collision between two objects. They may confuse this idea with situations where the net force on an object is zero and the motion of the object isn't changing. This is an instance of Newton's first law, whereas the former is Newton's third law.

Some students may have a good understanding that larger net forces are associated with larger changes in motion and that larger masses are harder to speed up or slow down than smaller masses, but students may have difficulty thinking about three variables (force, mass, and change in motion) at once.

Other prior conceptions students may have on related ideas are documented by the American Association for the Advancement of Science, Project 2061. (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**)

GUIDANCE FOR DEVELOPING YOUR WORD WALL

This unit refers to two categories of academic language (i.e., vocabulary). Most often in this unit, students will have experiences with and discussions about science ideas before they know the specific vocabulary word that names that idea. After students have developed a deep understanding of a science idea through these experiences, and sometimes because they are looking for a more-efficient way to express that idea, they have "earned" that word and can add the specific term to the class Word Wall. These "words we earn" should be recorded on the Word Wall using the students' own definition whenever possible. On the other hand, "words we encounter" are "given" to students in the course of a reading, video, or other activity, often with a definition clearly stated in the text. Sometimes, words we encounter are helpful just in that lesson and need not be recorded on the Word Wall. However, if a word we encounter will be frequently referred to throughout the unit, it should be added to the Word Wall. As such, the Word Wall becomes an ongoing collection of words we will continue to use, including all the words we earn in the unit and possibly a few key words we encounter.

The words we earn and words we encounter in this unit are listed in this document and in each lesson to help prepare and to avoid introducing a word before students have earned it. They are not intended as a vocabulary list for students to study before a lesson, as that would undermine the authentic and lasting connection students can make with these words when they are allowed to experience them first as ideas they're trying to figure out. It is best for students if you wait and create cards for the Word Wall in the moment, using definitions and pictorial representations that the class develops together as they discuss their experiences in the lesson. When they co-create the posted meaning of the word, students "own" the word—it honors their use of language and connects their specific experiences to the vocabulary of science beyond their classroom. It is especially important for emergent multilingual students to have a reference for this important vocabulary which includes an accessible definition and visual support. Sometimes creating Word Wall cards in the moment is a challenge. The *Teacher Guide* provides a suggested definition for each term to support you in helping your class develop a student-friendly definition that is also scientifically accurate. If you keep one Word Wall in your classroom for several sections of students, you might choose to record each class's definition separately and then propose an "official" definition to post the next day that captures the collected meaning.

Lesson	Words we earn	Words we encounter
1	collision	
2	force, kinetic energy, damage	
3	contact force, deformation	
4	best fit line, elastic limit, breaking point	
5	peak force	
6		concussion, axon
7		
8	stored (potential) energy	air resistance, friction
9	air resistance, friction	
10		
11		criteria, constraints, stakeholders (earned or encountered in *Cup Design Unit*, *Tsunami Unit*, and *Homemade Heater Unit*)
12		
13		
14		trade-off (earned previously in *Tsunami Unit*)
15		

TEACHING SCIENCE LITERACY

How does the Core Knowledge Science Literacy routine integrate with the unit investigations?

The Core Knowledge Science Literacy Student Reader and the weekly Science Literacy routine layer varied reading opportunities into the science unit. In their lives after graduating from high school, most students will not become scientists. They will no longer routinely participate in guided investigations to figure out how phenomena work. They will, however, read text about science and scientific claims, day in and day out. The ability to learn and think about science through reading is a skill unto itself and is important in tandem with investigative learning. It is natural to primarily associate emerging literacy with reading and writing instruction at the elementary level, but middle school is an important time to hone literacy skills—specifically in science in the era of politicization of science topics, polarization among adults, and proliferation of misinformation on social media. Detection and construction of well-reasoned explanations are important not just in science, but throughout everyday life. Using claims and evidence in reasoning is the way that thoughtful people think about things, and writing is thinking in print. Students become voters as they emerge from high school, so it is important that they acquire skills for detection of faulty information and practice legitimate communication about scientific issues in the years leading up to that civic benchmark.

Throughout the course of the unit's investigative lessons, students write in their science notebooks in some fashion almost daily, and significant emphasis is placed on the speaking and listening communication threads of the CCSS. The instructional design of the investigations is deliberately light on having students access disciplinary core content through text. NGSS emphasis is on students investigating phenomena along the storyline, so students' interaction with text within lessons is minimal and in service to the unit's storyline. The Science Literacy routine is integrated to exercise students' ability to interact with text about science topics. The routine presents students with short reading selections in a variety of styles, all related to the unit in which students are engaged. Each reading selection is accompanied by a brief but thoughtful writing exercise.

The subject matter of the reading selections ties back to the unit, but the timing for the assigned readings is such that students do not read about specific facets of the subject before they have completed the lessons to investigate that content. In other words, the reading enhances and reinforces the knowledge that students have built in previous lessons; the reading does not reveal beforehand the key takeaways that students are intended to learn through lesson interactions.

When is it done within a unit?

The Core Knowledge Science Literacy Student Reader includes one reading collection per week for every week of the unit. A week's reading collection relates to the lessons completed in the previous week. The reading is assigned at the beginning of the week with the accompanying writing exercise due at the end of the week.

The reading and writing exercises are designed to be completed by students independently, with brief, supporting, teacher-facilitated discussions at the beginning, midpoint, and end of the week.

How do students typically represent their thinking as part of the routine?

Students generate a written product associated with each reading selection. The products are varied in form and include graphic organizers, concept maps, cartoons, memes, infographics, storyboards, outlines, and paragraphs. The complexity of the products increases from week to week, with the final product for the unit being a single, thoughtfully reasoned, and well-constructed paragraph.

Put Yourself in This Scene

Literacy Objective

✓ Initiate thinking about the need to evaluate information in text and images.

Literacy Activity

- Read a brief scenario to pique interest, launch discussion, and begin to frame expectations.

Instructional Resources

Student Reader

Preface

Science Literacy Student Reader, Preface
"Put Yourself in This Scene"

No Prerequisite Investigation

The reading of the Preface is appropriate during the first week of unit instruction. The reading does not preemptively tell students facts about the topic that they are intended to learn throughout the course of their investigations.

Standards and Dimensions

NGSS

Disciplinary Core Idea PS2.A: Forces and Motion For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law).

Science and Engineering Practices: Obtaining, Evaluating, and Communicating Information; Asking Questions and Defining Problems

Crosscutting Concept: Cause and Effect

CCSS

English Language Arts

RST.6-8.2: Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions.

RST.6-8.10: By the end of grade 8, read and comprehend science/technical texts in the grades 6-8 text complexity band independently and proficiently.

Core Vocabulary

Core Vocabulary: Core Vocabulary terms are those that students should learn to use accurately in discussion and in written responses. During facilitation of learning, expose students repeatedly to these terms. No Core Vocabulary terms are highlighted in the Preface.

Language of Instruction: The Language of Instruction consists of additional terms, not considered a part of Core Vocabulary, that you should use when talking about any concepts in this exercise. Students will benefit from your modeling the use of these words without the expectation that students will use or explain the words themselves.

energy	**gravity**	**mass**
scientific literacy	**speed**	

A Glossary at the end of the Science Literacy Student Reader lists definitions for Core Vocabulary and selected Language of Instruction.

1. Plan ahead.

Determine your pacing to introduce the reading selections, check in with students on their progress, and discuss the reading content and writing exercise. If you are performing Science Literacy as a structured, weekly routine, you might implement a schedule like this:

- Monday: Designate a ten-minute period at the beginning of the week to introduce students to the Science Literacy Student Reader.
- Friday: Set aside time at the end of the week to facilitate a brief discussion about the reading.

2. Preview the assignment and set expectations. (Monday)

- Let students know that for the Science Literacy routine, they will read independently and then complete short writing assignments. The reading selections relate to topics they will be exploring in their Contact Forces unit science investigations.
- The reading and writing will typically be completed outside of class (unless you have available class time to allocate).
- The first week's reading is a short introductory segment in the book, and there is no accompanying writing exercise as the unit is getting started.
- The class will discuss the reading together at the end of the week.

SUPPORT—The Preface about the floating platform with diving boards scenario is written at approximately Lexile 1100–1200, which leans toward the high end of the expected text complexity band for middle school. You may wish to introduce a word identification and comprehension convention into your routine to support struggling readers. Hang an envelope near the door with the label, "When we talk about the next reading selection, I could use a little more help understanding the word(s). . . " Encourage students, as they are reading, to jot words, phrases, or sentences that they are unclear about onto small scraps of paper and tuck them into the envelope at any time preceding the discussion of the reading. Whenever you facilitate class discussion about a reading selection, check the envelope first, and layer in added examples and repeat definitions to help students build comprehension and fluency for terms or complex sentences about which they have revealed they are uncertain.

3. Facilitate discussion.

(FRIDAY)

Facilitate a brief class discussion about the Science Literacy Student Reader Preface, entitled "Put Yourself in This Scene."

Pages 2–3 **Suggested prompts**	**Sample student responses**
How would you summarize the "scene" referred to in the title?	*A group of friends are at a lake and discussing the differences in jumping or diving off a floating platform or off diving boards on the platform at different heights.* *It describes a discussion among friends about how it will feel to jump or dive into water from various heights above the water.*
Were you ever in a situation like the one in this scene? How did you decide what to do?	*I decided not to jump at all.* *I didn't want to risk jumping from the high board.*
What's your experience with jumping or diving into water? Does it feel different from different heights?	*I once did a cannonball jump off the high board, and it hurt.* *The high board hurts more than jumping off the edge of a pool.* *I saw a video in which a diver tried different board heights, and he said jumping from the lower boards felt about the same on his feet but the 10-meter board really hurt his feet.*
What factors might be involved in how much it hurts to jump into water?	*height above water* *speed of my fall* *how much I weigh* *the amount of energy when hitting the water* *clothes I am wearing* *what part of my body hits the water first* *how much of my body hits the water first, for example, the whole bottom of my foot or the tips of my toes* *whether you jump from a springboard or the deck of a platform* *kind of water—pool, lake, ocean*

Student Reader

Preface

SUPPORT—If you are using the recommended word envelope convention, check the envelope to see if it contains any words, phrases, or sentences that students need help understanding. Read key sentences aloud, and provide concise explanation.

Pages 2–3 **Suggested prompts**	**Sample student responses**
What are some testable questions that could be answered by collecting data in a scientific investigation?	*How does the height above the water of a falling object affect its impact with water?* *How does the speed of a falling object affect its impact with water?* *How does the mass/weight of a falling object affect its impact with water?* *How does the volume of a falling object affect its impact with water?* *How does the surface area of a falling object affect its impact with water?* *What clothing or gear can reduce the impact of jumping into water from a great height?*
If you want to learn more about this topic before experimenting using science materials, what sources would you use?	*Ask a reference librarian to point to information.* *Ask an expert, such as a diving coach or a physical science teacher.* *Search for videos online.* *Read web pages online.* *Ask a question on social media or on a discussion website.*
How do scientifically literate people decide which online sources are most reliable?	*If they use sources the reference librarian recommends, such as online encyclopedias, the sources should be reliable.* *If they use regular websites or social media, they need to check to see if the person posting has a science background.* *If they watch videos, they should stick with the videos from sources that are likely to be accurate, such as colleges or science museums.*

KEY IDEA—Point out that, without an investigation into the cause-and-effect relationships involved when jumping or diving into water, it's hard to know which of the friends is correct. Both the investigations and the reading selections in the unit ahead will help students advance to a place where they have more knowledge to apply to the scenario, and they will circle back to the topic of collisions between the human body and water when jumping from different heights at the end of the unit.

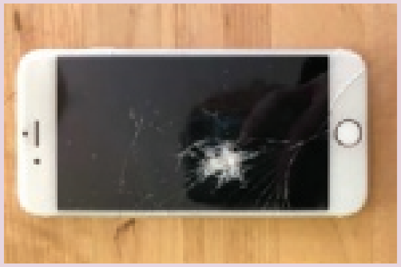
What happens when two things hit each other?

Previous Lesson *There is no previous lesson.*

This Lesson

Anchoring Phenomenon

3 DAYS



We share our experiences with cell phones breaking and demonstrate some ways they have broken. We brainstorm related phenomena (other objects that were damaged in a collision and examples where there was no damage). We identify factors and variables that can cause some fragile objects to become damaged more than others. We develop a model to describe visible changes happening to the objects in a collision and nonvisible interactions occurring as well. We develop questions for our Driving Question Board (DQB) and possible investigations we could do to answer these questions.

Next Lesson *We will explore colliding objects and record observations about changes in their motion and shape. We will analyze slow-motion videos of some of these collisions. We will develop a model to represent what we know about energy transfer and forces occurring in collisions when we see changes in motion of objects, shape of objects, or damage to objects.*

Building Toward NGSS

MS-PS2-1, MS-PS2-2, MS-PS3-1, MS-ETS1-2, MS-ETS1-3, MS-LS1-8

What Students Will Do

1.A Develop a model to describe interactions between two objects as they collide and show the changes that occur in the structure of both objects when one object is damaged as a result and also when neither object is damaged as a result.

1.B Ask questions that arise from observations of collisions between two objects in order to seek additional information about factors (causes) that might affect the outcome of such collisions.

What Students Will Figure Out

- In a collision between two objects, the objects make contact with each other; sometimes something is damaged, but not always.
- Different factors or variables may cause objects to be damaged or not from a collision.

Lesson 1 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	15 min	**SET THE STAGE FOR A NEW PHENOMENON** Share cell phone damage data from a news article to elicit student experiences. Have some students reenact some phone breaking scenarios.	A-C	3 blank pieces of chart paper, small stack of blank 8.5″ × 11″ paper, 2 different color markers, 4 CD cases, 5 sets of goggles, Different Collisions poster
2	5 min	**BRAINSTORMING RELATED PHENOMENA** Classify related phenomena based upon types of collisions and damage or no damage.	D	2-3 red index cards per student, 2-3 green index cards per student, Different Collisions poster, Related Phenomena poster
3	7 min	**SHARE AND COMPARE RELATED PHENOMENA** Share related phenomena index cards and compare the interactions with other students.	E-F	related phenomena index cards, Related Phenomena poster, 3 areas of the room labeled “A” “B” and “C”
4	6 min	**SET UP NOTEBOOKS AND STOP AND JOT COLLISION FACTORS** Identify and record variables and factors that affect damage in a collision.	G	Different Collisions poster, Related Phenomena poster, tape
5	12 min	**CREATE INITIAL MODELS** Draw a model to explain the interactions occurring between the objects during a collision and the factors and variables that might contribute to a different outcome (damage or no damage) in a collision.	H-I	*Initial Model: Objects During Collisions*, *Object Interactions During a Collision*
				End of day 1
6	5 min	**ESTABLISH SCIENTISTS CIRCLE AND SHARE INITIAL MODELS** Share initial model ideas with a partner.	J	*Initial Model: Objects During Collisions*, *Object Interactions During a Collision*, tape
7	10 min	**ESTABLISH SHARED NORMS** Develop shared norms for the learning community before the first Consensus Discussion and model.	K	*Science Classroom Norms*, scissors, tape
8	25 min	**DEVELOP INITIAL CONSENSUS MODEL DISCUSSION AND RELATED QUESTIONS** Develop a whole-group record of what we agree on and where we have competing ideas across the initial models. Record some initial questions for the Driving Question Board.	L-M	*Initial Model: Objects During Collisions*, *Object Interactions During a Collision*, markers, Consensus Model for Collisions poster

Part	Duration	Summary	Slide	Materials
9	5 min	**DETERMINE FACTORS AND VARIABLES THAT AFFECT DAMAGE** Make a public record of our ideas about what factors and variables contribute to damage in a collision.	N	Factors and Variables poster, markers
				End of day 2
10	3 min	**NAVIGATION** Ask students to review the norms again and select a norm to focus on for class today.	O	*Science Classroom Norms*
11	7 min	**REVISIT FACTORS AND VARIABLES POSTER**	P-Q	1-2 index cards, marker, Factors and Variables poster
12	28 min	**DRIVING QUESTION BOARD AND IDEAS FOR INVESTIGATIONS** Gather in a Scientists Circle to construct a Driving Question Board and develop ideas for potential investigations.	R-S	*Initial Model: Objects During Collisions*, *Object Interactions During a Collision*, Driving Question Board, Consensus Model for Collisions poster, index cards, tape, chart paper, markers
13	2 min	**NAVIGATE TO NEXT LESSON** We end the lesson anticipating where we are headed next to investigate this phenomenon.	T	
14	3 min	**REVISITING NORMS** Prompt students to revisit how they did on the norms in class today.	U	*Science Classroom Norms*
15	2 min	**ADD TO THE TABLE OF CONTENTS** Provide an example of how to fill out the table of contents in their notebooks to reference each piece of work they developed so far.		chart paper, markers
				End of day 3

Lesson 1 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide** **Student Work Pages**	• science notebook • 2-3 red index cards per student • 2-3 green index cards per student • related phenomena index cards • *Initial Model: Objects During Collisions* • *Object Interactions During a Collision* • *Science Classroom Norms* • scissors • tape • 1-2 index cards • marker		• 3 blank pieces of chart paper • small stack of blank 8.5″ × 11″ paper • 2 different color markers • 4 CD cases • 5 sets of goggles • Different Collisions poster • Related Phenomena poster • 3 areas of the room labeled "A" "B" and "C" • tape • markers • Consensus Model for Collisions poster • Factors and Variables poster • Driving Question Board • index cards • chart paper

Materials preparation (25 minutes)

Online Resources

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Create a Different Collisions poster using one piece of chart paper.

Create a Related Phenomena poster using two pieces of chart paper.

- Include the title "Related Phenomena" at the top.
- Create 3 rows: A, B, and C.
- Write "red = damage" and "green = no damage" in the upper-left corner.
- Up to 3 pieces of chart paper can be used for larger classes.
- Label 3 different areas of the room "A", "B", and "C" that allow plenty of space for students to congregate in those areas.

Create a Consensus Model for Collisions poster.

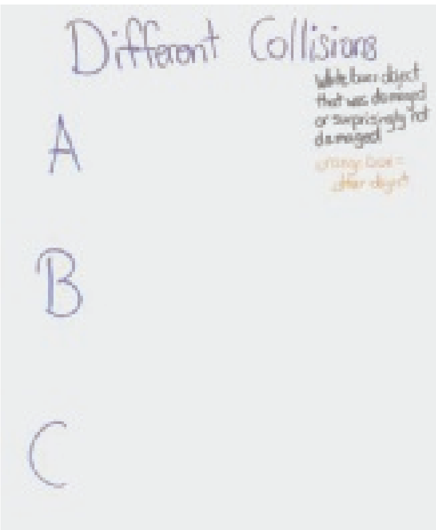
- Include the title "Collisions" at the top.
- Draw a table with 4 columns x 2 rows (plus room for column heads).

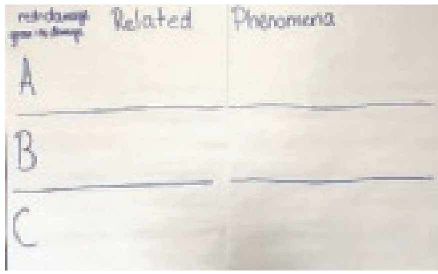
- Column #1 head: ”Result”
- List ”Damage” and ”No damage” in the 2 boxes below the ”Result” head.
- Column #2 head: “Time point #1 at the moment of contact”.
- Column #3 head: ”Changes we can see” (in one color) and ”Interactions we cannot see” (in a different color).
- Column #4 head: “Time point #2 a split second later”

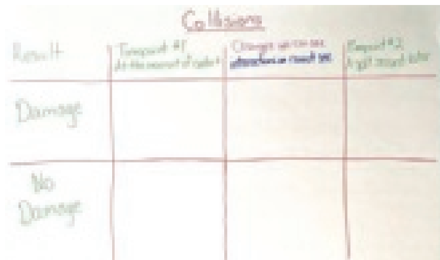
Create a Factors and Variables poster with the title “What factors and variables could influence whether a collision causes damage?” Create the following posters prior to this lesson:

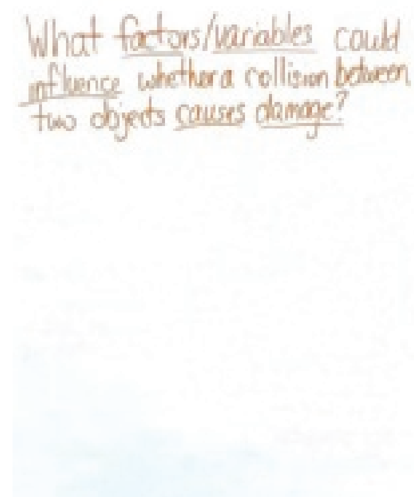
Download the Communicating in Scientific Ways chart from the website and post it in your classroom or add it to students’ notebooks. The file can be used as a poster or as a handout.

Determine where to set up the Driving Question Board so that students can gather around it.









Lesson 1 • Where We Are Going and NOT Going

Where We Are Going

This lesson is meant to draw out students’ prior experiences with collisions and to help them consider what might determine whether something breaks in a collision. This is an opportunity to pre-assess students’ engagement in all three dimensions of NGSS to explain a phenomenon. There are prompts in the initial modeling task that ask students to engage in two elements of the modeling practice related to representing descriptive aspects of the phenomena as well as unobservable mechanisms. Students are prompted to explain the mechanisms that caused the observable changes, which will provide an opportunity to bring related DCIs from prior grades: grade 4 (energy transfer in collisions), grade 2 (objects pull or push each other when they collide), and the middle school grade band explanation (such as equal force pairs between the two objects in contact). There are phrases in the prompts that ask students to consider related elements of CCCs as well, particularly cause and effect, systems and system models, and stability and change.

You may also see some students developing particle-level representations for changes happening to the matter in the system in their initial models, based on their extensive work in developing such models in prior units: *Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)*, *Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit)*, *Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)*, *Unit 7.2: How can we help people design a flameless heater? (Homemade Heater Unit)*, *Unit 7.3: How do things inside our bodies work together to make us feel the way we do? (Inside Our Bodies Unit)*, and *Unit 7.4: Where does food come from, and where does it go next? (Maple Syrup Unit)*.

Students may be curious about which materials are fragile and why or how to protect things that break easily. Students may also be curious about how the motion or mass or size of the objects before the collision affects the outcome. This curiosity will seed future investigations.

Students are likely to identify many of the factors or variables that influence whether an object does or does not get damaged in a collision, such as mass, speed, area of contact, and material type or thickness. The factors and variables identified will motivate many of the subsequent lesson questions and investigations in the first half of the unit.

Where We Are NOT Going

If students do not talk about physics concepts like force, energy, or motion in this first lesson, do not introduce them yet. These words will be explicitly introduced in the next lesson. This lesson, while focusing on contact forces, will not yet ask students to understand or utilize the ideas of positional energy, differences in materials, or elastic limits. These ideas will be developed in future lessons. Students may have a partial understanding of energy transfer from *Cup Design Unit*, *Tsunami Unit*, *Storms Unit*, *Bath Bombs Unit*, and *Homemade Heater Unit*. While students may represent in their models that this energy transfer is occurring, later lessons will help students understand the relationships among mass, speed, and damage due to the transfer of energy across a medium.

1. Set the stage for a new phenomenon.

15 MIN

Materials: 3 blank pieces of chart paper, small stack of blank 8.5″ × 11″ paper, 2 different color markers, 4 CD cases, 5 sets of goggles, Different Collisions poster

Introduce cell phone damage information. Display **slide A**. Say, *I came across some interesting data about cell phone damages. Listen to the things I learned!* Read each statistic aloud.

- *Americans break 2 smartphone screens every second.*
- *More than 50 million phone screens are cracked each year.*
- *An estimated 95 million phones were damaged in the world by dropping them.*
- *We spend $3.4 BILLION each year in replacing cracked screens—not counting the 38% of smartphone owners who don't replace them at all.*
- *27% of people said that their phone was in a case when they broke it.*

Say, *This seems like a lot of cell phone damage happening in our world. That got me wondering how common this sort of phenomenon is in our classroom community. Have any of you ever experienced cell phone damage before?*

Instruct students to raise their hands if they have experienced a situation where they have seen a phone get damaged.

Elicit student experiences. Display **slide B**. Ask students to turn and talk with a partner about the slide question: "Have you or someone you know ever broken a phone? What caused it to break? Describe your experiences."

Additional Guidance

As students are detailing their experiences, listen for instances where a stationary phone has been hit by a moving object, a moving phone has hit a stationary object (dropped on floor, thrown, and so forth), or a phone that is moving has been hit with another moving object. These instances can be leveraged in the next step for recruiting student volunteers to reenact their experiences.

Say, *Wow, we seem to have a lot of experience with damaging cell phones! It sounds like some of you have been the ones to create the damage, and some of you have seen them damaged before.*

Additional Guidance

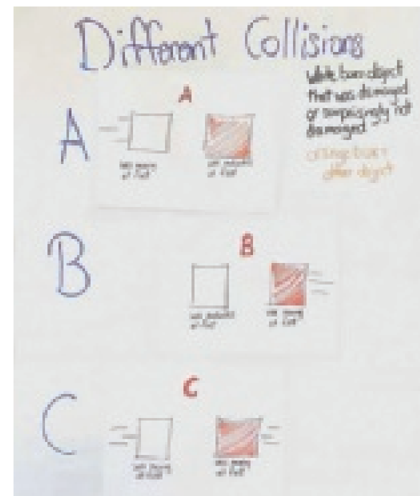
The word *damage* will be defined later in Lesson 2. At this point, students are identifying collisions that did or did not cause damage, and factors or variables that may contribute to damage. While it is important to develop a common working understanding of this word in later lessons, students' prior knowledge and conceptions of what this word means will suffice for the work in Lesson 1. Students will have an opportunity to develop a deeper understanding of this word in Lesson 2.

Introduce a CD case to represent a phone in collisions. Display **slide C**. Say, *I would love to hear about your experiences with phones breaking, but sometimes it's easier for us to understand a situation where something occurred when we can see a representation of how it happened rather than just hearing about it. Phones are expensive, so I have a CD case here that we are going to use as a substitute for a phone. I thought we could use this as a manipulative to represent what happened to the phone when it got damaged.*

Demonstrate phone breaking experiences. Select one volunteer at a time to come up in front of the class and demonstrate what happened with the cell phone when it broke. Let students know it's OK if what they show us ends up causing the CD case to break too, as we want to try to understand the interactions that happened and the results as accurately as possible. Remind them to be responsible and avoid moving the CD case or any other object in a direction that might remotely come in contact with another living thing or fragile object.

Safety Precautions

Review any safety guidelines and have students wear goggles who are demonstrating the collision and standing or sitting near the demonstration during this and all future investigations in this unit. Setting up strong boundaries and expectations with the demonstrations is key. Students will show a variety of collisions with cell phones during this stage. Some possible scenarios to expect are dropping the CD case on different objects, slamming objects onto the CD case, ramming objects into the CD case (e.g., foot, backpack, chair), and flinging the CD case at a wall. Asking demonstration volunteers if the interaction they are about to enact is safe to show with others around and if it can be safely done in the classroom may help ensure safety as students are demonstrating their experiences.



Use the prompts below to elicit experiences from student volunteers so that you get at least one example that would represent each of the three collision types: A, B, and C.

As each student shares their experience, create a diagram on a blank piece of paper using squares to represent the two objects that collided. After creating each diagram, attach it on the Different Collisions poster. Draw large enough for students to see. The diagrams will become part of an anchor chart for students to refer to later. The three diagrams (A, B, C; that you will finish drawing in the subsequent conversation) should be similar to ones shown here. As you are drawing, remember to represent the phone as a white box and the other object as a shaded box instead of the actual objects being described by students. This will help students later to transfer and categorize the general diagrammatic representations into related phenomena experiences.

Key Ideas

The purpose of this discussion is for students to determine that there are 3 main types of collisions, and those types may or may not result in damage. As students share their experiences with phones, listen for these three types of collisions to emerge:

A. A fragile object moved toward and hit another object that was motionless.

B. A fragile object was motionless and was hit by another object that was moving.

C. A fragile object was moving and was hit by another object that was moving.

The prompts and example responses below are meant to elicit the three different types of collisions.

What to listen for: Listen for students to give examples of each collision type. Each prompt section below is meant to clarify what was moving and what was not moving. The suggested prompts can be used to ensure that all 3 collision types are present, but if other prompts are used, make sure they elicit experiences, clarify what was moving and what was motionless, represent all 3 types of collisions, and provide for teacher diagram-drawing opportunities.

These collision types will be referenced and leveraged in later lessons to help explain why some objects become damaged and others are surprisingly not damaged.

Students will get a chance to revisit these ideas and show progress towards figuring this out during the Lesson 6, Lesson 9, and Lesson 13 assessments.

Suggested prompts	Sample student responses	Follow-up questions
Most of the interesting figures from the slide were about phones getting damaged by dropping them or accidentally throwing them. Does anyone have any examples they can show us where the phone was moving and it ended up hitting something that was not moving?	*I dropped my phone down a flight of stairs.*	*Oh wow! That is not good. I'll try to draw what happened as you show us how it happened. What was moving?*
	The phone was moving.	*So the stairs were motionless?*
	Nothing else was moving. It just hit the stairs.	*So it sounds like we have a fragile object moving toward and hitting something motionless. Cool. Let's label this collision type "A".* *(Draw representation A for this scenario.)*
Are there any examples where things were moving and then damaged the phone? Is the phone always the thing that is moving when it gets damaged, or can it be motionless and get hit by something else moving?	*Something else can be moving and hit it to make it break, like when I accidentally dropped my book bag on top of my phone.*	*Wow that's interesting! Show us what happened. Let me draw this out so we can all see what happened as you show us. What was moving?*
	The bag was moving.	*Was the phone not moving?*
	The phone was not moving.	*So the moving book bag hit the nonmoving, fragile phone, correct? Awesome. Let's call this type B.* *(Draw representation B for this scenario.)*

Suggested prompts	Sample student responses	Follow-up questions
Are there any other instances where things were moving to damage the phone? Does every phone-breaking story have one thing that wasn't moving, or can both things move and run into each other to cause damage?	*Two things can definitely run into each other to cause damage!*	*(Poll students.) Has anyone ever had this happen to them or seen this happen? Raise your hand if this has happened to you or someone you know.*
	(Some students will likely raise their hand.)	*Does anyone have an example they would like to share where both the phone and something else were moving and hit each other to cause damage?*
	I saw a video of someone throwing a phone like a baseball and it getting hit with a baseball bat. It did not turn out well for the phone.	*That sounds like it really got damaged! Show us what happened. Let me draw this one too. What was moving?*
	Both objects were—the bat and the phone.	*So everything was moving?*
	Yes.	*OK. Let's write type "C" on this piece of paper.* *(Draw representation C for this scenario.)*

Discuss and alter frames of reference. Revisit the drawings and place the Different Collisions poster in a spot that is easily viewable for students, if not already in a prominent spot in the classroom. First, remove the piece of paper with collision type A that shows the diagram that has a moving, fragile object colliding with a motionless object (collisions type A). Use the prompts below to help students consider changes to the frame of reference.

Suggested prompts	Sample student response
Look at this diagram we drew of the collision type that went with our phone facts we read. It shows the moving phone coming in from (specify direction) before hitting an object that is not moving. Would this still show the same type of interaction if I rotated the picture to the left? *(Rotate the diagram clockwise.)*	*Yes, because the phone is still running into something that is not moving.*

Suggested prompts	Sample student response
Do we still have the same thing moving and the same thing motionless before they hit?	*Yeah, it still has the phone as the only thing moving before it hits the other thing. The same objects are still moving and not moving.*
What if I rotate it to the left one more time?	*You still have one object moving into another object. It's the same.*
So even if we change the direction, we still have the same object moving and the same object motionless?	*Yeah, the same object is moving, it's just coming from a different direction.*

Return collision type A back to the Different Collisions poster. If needed, remove the collision types B and C from the Different Collisions poster and repeat this line of questioning with collision types B and C.

Additional Guidance

If students bring up the idea of gravity, acknowledge the idea by saying: *So it sounds like you are thinking about forces in the system too. That is a really useful way to consider what is happening in any system where we are tracking motion of objects in the system. Right now our diagrams are only showing which objects are in motion before the collision to see if we can classify all our collisions in terms of which objects were in motion at first. We may need to consider how to add forces if we think that is helping explain something about the collision too.*

In later lessons, gravity will be used to provide a force to move carts on a ramp for data collection purposes. While gravity is not being addressed or explained in this unit, the force of gravity will be recognized and utilized.

Categorize remaining interactions. Ask students if they have any other stories that would be represented differently than our drawings. If a student says yes, have them demonstrate the interaction while you map it out on a blank piece of paper. Compare the interaction to the other collision types on the chart, turning it to see if the interaction matches any existing collision type scenarios. Help students draw the conclusion that the scenario is already on the collision types board by simply changing the frame of reference.

Key Ideas

Part of the DCI for PS2.A states that, *All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame …. In order to share information with other people, these choices must also be shared.* The idea of an arbitrarily chosen reference frame was introduced here when you physically rotated the diagrams and asked students whether the diagram still represents the same system. You are further reinforcing this idea by asking whether all the other collisions can be categorized using one of three system diagrams (A, B, and C).

Introduce the word *collision* to students.*

*** Attending to Equity**
Emergent Multilingual Learners: For students who are learning English or who need support following a whole-group discussion, it can be helpful to use gestures in addition to talking. For example, as you describe a phone hitting a wall, demonstrate the collision by holding a phone (or another object to represent a phone) in your hand and moving it slowly toward the wall.

*** Attending to Equity**
Emergent Multilingual Learners: A Word Wall will become a useful space for recording a shared meaning of new words as students develop a deeper meaning for them. When developing new vocabulary, some strategies that may benefit emergent language learners are to use student-friendly definitions, make connections to cognate words when possible, and include a visual representation of the word. You have now developed a visual representation of the word *collision* that you can refer to over the course of this unit. After students have had time to develop a conceptual model or understanding for these words, they will no longer need the visual representation.

Suggested prompt	Sample student responses
We've talked about our experiences and made some observations about what happens when a phone gets damaged. I've noticed we've all been using different words to describe that moment when the objects hit or run into each other. Can someone share another word that they have been using to describe this?	*Smash.* *Bump.* *Crash.*

Use the CD case, if necessary, to enact the moment when the "phone" touches another object for any of the three collision scenario types.*

Say, *There are a lot of words we can use to describe this phenomenon. When scientists describe this sort of phenomenon, where a moving object hits or runs into another object, they refer to it as a* collision.

Display the poster that says "Different collisions".

Motivate related phenomena. Say, *These categories of collisions could be useful for thinking about other related phenomena where something other than a phone was involved in a collision. But not all collisions result in damage. Think of examples where something other than a phone was damaged in the collision. I also want you to think of examples where you were surprised that something other than a phone was* not *damaged in a collision.*

2. Brainstorming Related Phenomena

5 MIN

Materials: science notebook, 2-3 red index cards per student, 2-3 green index cards per student, Different Collisions poster, Related Phenomena poster

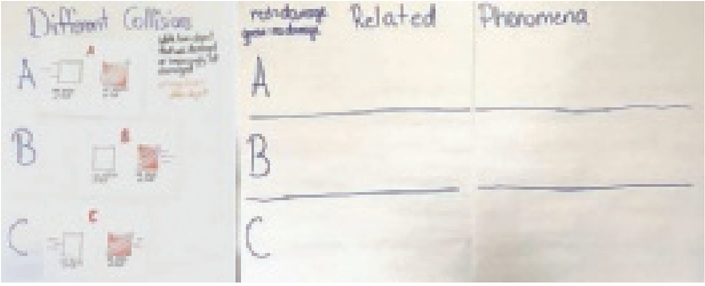
Document related phenomena on index cards. Project **slide D**. Read through the directions on the slide. Pass out 2-3 red and green index cards to each student. If red and green index cards are not being used, update slide D and slide E to reflect the colors of the index cards or sticky note being used.

Prompt students to record at least one collision where something has been damaged on red cards and at least one collision where something was surprisingly not damaged on green cards. For each thing listed, students should identify the objects that came into contact with each other during the collision and underline the object or objects that were moving before the collision occurred. Only one collision example should be written on each card.

Provide students approximately 5 minutes to generate and record their related phenomena cards. Encourage students to use as many cards as they need as they think of other examples.

Hang the Different Collisions poster to the left of the Related Phenomena poster. Then, circulate during the remaining time to help any student who may become stuck while trying to brainstorm examples.

With about a minute left, remind students to go back over their index cards and make sure that they have identified the objects that came into contact with each other during the collision and have underlined which objects were moving before the collision occurred.



3. Share and compare related phenomena.

7 MIN

Materials: science notebook, related phenomena index cards, Related Phenomena poster, 3 areas of the room labeled "A" "B" and "C"

Revisit the different collision types. Display **slide E**. Read through slide E and go over each type of collision, emphasizing what objects were moving or not moving before the collision. A quick reference table is given below.

Collision type	Motion of the objects before the collision and the resulting damage
A	A moving object was damaged OR wasn't damaged when it collided with a motionless object.
B	A motionless object was damaged OR wasn't damaged when a moving object collided with it.
C	A moving object was damaged OR wasn't damaged when it collided with another moving object.

Say, *In class we have identified three different types of collisions. Let's sort our related collisions into these categories and see if we notice any patterns or factors that may contribute to damage in the collisions. Look at your index cards and write the collision type at the top of each one—A. B. or C.*

Have students ask an elbow partner to quickly check their collision types. If there is debate on the collision type, help students sort out the appropriate type individually.

Share related phenomena. Display **slide F**. Students will organize themselves based upon related phenomena and share their phenomena with a partner.* During this time students will be developing the idea of different factors or variables that impact damage.

Say, *In a moment, you will get the chance to share your related phenomena with someone else. There are 3 sections of the room labeled A, B, and C. When I ask you to, you will look at the collision type on one of your cards and go to the area with that collision type. Once you are there, find someone and share your collision. As you share, be thinking about what is similar and different between the two collisions.*

Ask students to look at one of their red, damage cards first. Direct them to move to the area of the room that matches their collision type. Give students 2 minutes to share and compare and contrast with their partners. After the two minutes are up, ask students to look at one of their green, no-damage cards. Direct students to move to the area that matches their green card collision type. Give students 2 minutes to share and compare and contrast with their partners.

Tell students to hand in all of their index cards and return to their seats.

*** Attending to Equity**

Universal Design for Learning: It is important to organize activities in ways that create opportunities to support student *engagement* in meaningful, accountable talk by emphasizing socially safe activity structures (e.g., small-group or partner work before a whole-class discussion). This is especially beneficial to emergent multilingual students. For this reason, partner talk or small-group talk should precede whole-group sharing to give students an opportunity to share their ideas with one or two peers before going public with the whole class.

4. Set up notebooks and stop and jot collision factors.

6 MIN

Materials: science notebook, Different Collisions poster, Related Phenomena poster, tape

Prepare science notebooks. Say, *It seems like we were finding a lot of similarities, differences, and maybe even some important factors and variables across our collisions. Let's make sure to record these ideas!*

Science Notebook

If this is the first unit of your 8th grade course and you have not yet set up and organized students' science notebooks, you need to include additional time to do so now. Have students organize their notebooks using a format that will be easy for them and you to maintain across the year. Helpful tips for keeping the notebooks organized include the following:

- Number pages so that students can easily refer to their work (e.g., models, data sets) during collaborative discussions.
- Maintain a table of contents and update it throughout the unit. Reserve at least 4 pages (2 sheets front and back) for the table of contents for a single unit. The table of contents can be at the front of the notebook for all units within or at the beginning of each new unit within the notebook.
- Give each page a recognizable title that can be added to the table of contents after those artifacts are added to the notebook (students will do this at the end of this lesson).
- After the table of contents, reserve the next 20 pages (10 sheets front and back) for their Progress Tracker for the unit. This is the place where students will individually reflect on their progress and also add key consensus modeling work completed by the class.

For more information on *Science Notebook Management*, refer to this section of the *Teacher Handbook*.

Identifying factors in a collision. Project **slide G**. Ask students to begin a new page in their science notebook to set up the related T-chart.* Give students 4 minutes to record any patterns they saw in the collisions they discussed.* Have students focus on looking for clues about possible factors or variables that would cause something to get damaged or not get damaged during a collision and record them on their charts. Some potential ideas for factors or variables include the following:

- mass of the object
- speed of the object
- direction of the object
- if the object was moving or not
- angle at which the object was struck
- material the object is made from

Additional Guidance

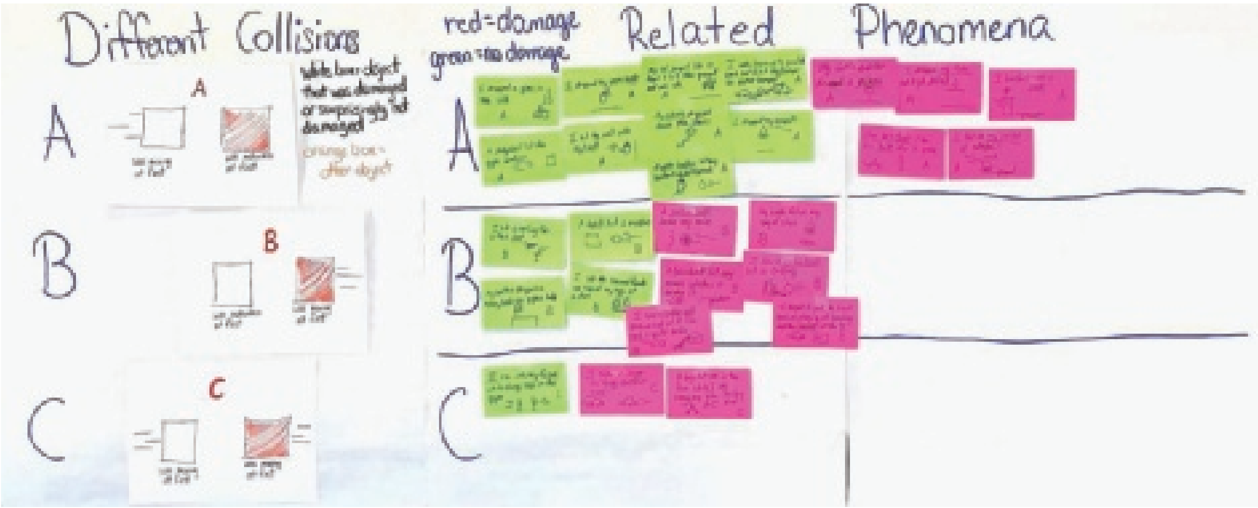
In previous units, students have had experience identifying variables that can affect a system. The connection between variables and cause and effect have been woven into multiple units, including *Cup Design Unit* and *Homemade Heater Unit*. There are multiple factors or causes for this phenomenon that influence its outcome, and this chart helps students identify variables to change in later lessons. If students are struggling with coming up with variables or factors that might have contributed to damage or no damage in a collision, lessons where variables have been altered from previous units can be referenced for ideas. One specific lesson to reference includes changing

*** Attending to Equity**
Universal Design for Learning: Keeping a science notebook allows students a space in which to reflect and communicate their developing understandings about science ideas and to track changes in their understandings. Students should be encouraged to record their ideas using linguistic (e.g., written words) and nonlinguistic (e.g., taping in photographs, creating drawings, tables, graphs, mathematical equations, and measurements) modes.

*** Attending to Equity**
Supporting Emergent Multilinguals: This is especially important for emerging multilingual students because making connections between written words and nonlinguistic representations helps students generate richer explanations of scientific phenomena.

variables within the cup system to affect the retention of energy from *Cup Design Unit*. Cause and effect can also be seen in *Tsunami Unit* where wave energy resulted in damage to breakwaters in a collision. Students may bring ideas from these units to aid them in their explanations and determination of factors and variables in a collision.

Organize related phenomena. While students complete their tables, use this independent writing time to tape the student-generated phenomena cards in the correct areas on the Related Phenomena poster. For larger classes, it is recommended to use 3 pieces of chart paper instead of 2 pieces to accommodate space for all index cards on the poster.



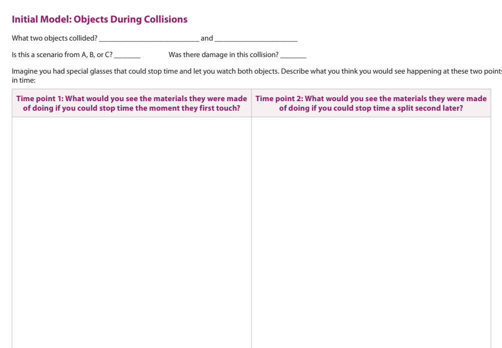
5. Create initial models.

12 MIN

Materials: *Initial Model: Objects During Collisions*, *Object Interactions During a Collision*, science notebook

Develop initial models of objects during a collision. Say, *Let's try to develop a model to explain what is happening when two things come into contact in a collision.* Display **slide H**.*

Distribute a copy of *Initial Model: Objects During Collisions* to each student. Tell students that they should put their name on their handout but don't add it to their notebooks yet, as you want to collect it at the end of the period to get a sense of what they are thinking. Ask students to look at the Related Phenomena poster where they listed examples of things that have been damaged or surprisingly not been damaged in collisions. Ask students to pick one of these examples to explain on their handout.



Initial Model: Objects During Collisions

What two objects collided? ______________________ and ____________________

Is this a scenario from A, B, or C? _______ Was there damage in this collision? _______

Imagine you had special glasses that could stop time and let you watch both objects. Describe what you think you would see happening at these two points in time:

Time point 1: What would you see the materials they were made of doing if you could stop time the moment they first touch?	Time point 2: What would you see the materials they were made of doing if you could stop time a split second later?

*** Supporting Students in Engaging in Developing and Using Models**

1. The word *model* means something specific in this context that it might not mean for students in other contexts. Remind students that in this classroom, a model is a picture and/or description that helps us explain something that happens in the world. We are asking students to make a model to help explain why something

Say, *You are going to use this handout to develop a model to show what interactions are happening between the objects during a collision. On the first line, list the two objects that collided. Did you choose an example that matched collision type A, B, or C? List which scenario you chose. Look at the next question: Was there damage in this collision? Write "yes" if there was damage and "no" if there was not damage.* Give students a minute to answer the first three questions on their handout before moving on to the boxes below.

Say, *In the space below, imagine you could slow time down and could also freeze or pause the collision at different points in time. What do you think you would see happening to the materials right at the moment the objects first touched or made contact with each other in the collision? That's this box on the left labeled "Time point 1". How about a split second later? That's the box on the right labeled "Time point 2". Draw and label or describe in words what you think you would see happening for both objects at each time point.*

Additional Guidance

If students need more room for their diagrams, you can have them record their ideas in their notebook directly instead of on the handout. They can take an entire notebook page turned sideways for their time point 1 and 2 drawings and use the facing page for their explanations. Note that this will take up two notebook pages instead of one.

After 3–4 minutes, distribute *Object Interactions During a Collision*. Project **slide I**. Say, *Look at the questions on this second handout and look at the model you just drew. The first question is asking you to think about what is happening with the objects between time point 1 and time point 2. What changes do you think you could see happening between those two points in time?*

The second question asks you to think about the interactions that you cannot see happening with the objects in a collision. What interactions between those two points in time do you think you couldn't see happening with those objects as they collided?

The third question wants you to think about what changes to these interactions might lead to more or less damage. When we are talking about their interactions, we are talking about the ways that they are acting on and affecting each other when they are touching. What changes to the way that they are acting on and affecting each other when they are touching would lead to more or less damage?

Give students the remaining time to consider the questions and respond.** At the end of the class period, have students hand in *Initial Model: Objects During Collisions* and *Object Interactions During a Collision* for a formative assessment. If students have constructed the initial models in their notebooks, have students hand in their notebooks.

Assessment Opportunity

Building towards: 1.A Develop a model to describe interactions between two objects as they collide and show the changes that occur in the structure of both objects when one object is damaged as a result and also when neither object is damaged as a result.

What to look for/listen for

- **Unobservable mechanisms:** Prompts in this task ask students to engage in two elements of the modeling practice related to representing descriptive aspects of the phenomena as well as unobservable mechanisms (energy transfer

gets damaged when it is involved in a collision. Like their work in previous units, such models should be trying to do more than just show what we can see; they should also try to represent any unobservable mechanisms that we think might be at work in the system.
2. Students take into account multiple factors that may contribute to damage in a collision. While it will be relatively intuitive for some students to attend to the ideas of variables changing in the system, some changes that are unobservable at the micro level must also be occurring. This focus on unobservable mechanisms is where students will likely need additional encouragement to make their thinking visible on paper. Such prompting is more likely to raise awareness that there is a gap in the current explanatory model (if the student can't think of any candidate mechanisms), or it may also help them connect to previous ideas about forces or energy they may have developed though prior instruction.

*** Supporting Students in Developing and Using Stability and Change**
Modeling and explaining visible changes provides students the opportunity to show understanding of Stability and Change. Grades 3-5 experiences

in collisions and objects pushing on each other when they collide). You may also see some students using particle-level representations to help explain changes occurring in the objects in the collison, based on their extensive work in developing such models in prior units.

- **Factors or variables** that cause the materials to break or not break in a collision, such as mass, speed, area of contact, material type and thickness, any other structural differences students wish to identify
- **Other connections to CCCs:** There are phrases in the prompts that ask students to consider connections to related elements of CCCs, particularly cause and effect, systems and system models, and stability and change. These may lead students to develop and use ideas that help them connect ideas about forces, energy, and changes occurring in the object. These ideas will be developed later in this unit. Here is a good opportunity to see if students are already making some of these connections:
    - In a collision, objects exert forces on each other; those forces cause energy to be transferred (effect) to or from the objects.
    - Each object in the collision (subsystem) exerts a force on the other object in the collision; these forces are equal in strength and opposite in direction.
    - These forces (cause) also result in some deformation (change or effect) of each object.
    - An object's structure (the type of materials it is made of and the shapes of those materials) affects how much it will deform and how much it will push back in a collision before breaking.
    - Deformation beyond a certain point results in damage (a permanent shape change); but deformation below that point does not (stability).
    - The amount of kinetic energy objects have in a system is related to the amount of energy that can be transferred between them and the amount of peak force they will apply to each other in a collision; the amount of kinetic energy is related to the mass and speed of the object.

What to do: If students do not include connections to any of these ideas listed above, that is OK for now. Students will build on and revise their models over the course of the unit. Make a copy of these explanatory models and compare them with what students show in their individual model and explanation at the end of Lesson Set 1 and the end of Lesson Set 2. You may also want to have students analyze their growth by comparing these artifacts related to the elements mentioned above.

End of day 1

6. Establish Scientists Circle and share initial models. 5 MIN

Materials: *Initial Model: Objects During Collisions*, *Object Interactions During a Collision*, science notebook, tape

Return materials to students. Return *Initial Model: Objects During Collisions* and *Object Interactions During a Collision* to science notebooks to students. If students used the loose handouts instead of recording in their science notebooks, give students time to attach the handouts to a notebook page using tape.

Form a Scientists Circle for the first time. Ask students to assemble their chairs in a circle and to bring their science notebooks and something to write with. Students will remain in the circle for all of class, though they will move among

should have accentuated that although some systems appear stable, they can change over time. By asking questions that allow students to dwell on the moment of impact and what happens shortly after the collision, prior conceptions about instantaneous damage can be uncovered. Students may believe that shape changes do not happen unless there is damage, or damage is only limited to the breaking of objects. At this point students are not expected to exhibit understanding of these ideas nor do they need to show changes at different scales (including the particle level) that occur over the duration of the collision. Over the course of the unit, students will develop an understanding of shape change that occurs during collisions, force pairs, and the interactions of objects in a collision.

*** Supporting Students in Three-Dimensional Learning**

This is an opportunity to pre-assess students' engagement in all three dimensions of NGSS to explain a phenomenon. There are prompts in this task that ask students to engage in two elements of the modeling practice related to representing descriptive aspects of the phenomena as well as unobservable mechanisms. Students are prompted to explain the mechanisms that caused partner, small-group, and whole-class discussions. This will help minimize the movement of chairs throughout the class period. As students get more comfortable with the Scientists Circle, they can move between it and other activity structures more quickly. Ideally, they will need to be able to see the slides and have access to a whiteboard, but if that is not possible, use only the whiteboard (or chart paper), which is where the more critical sensemaking will occur for the rest of the class.

Scientists Circle

You will form a Scientists Circle in many future lessons as well. Setting up the norms and logistics for forming, equitably participating in, and breaking down that space is important to do if this is your first time forming such a space. Having students sit in a circle so they can see and face one another can help build a sense of shared mission and community of learners working together. Returning to this Scientists Circle throughout the course of the unit to take stock of what the class has figured out and where they need to go next will be an important tool in helping the class take on greater agency in steering the direction of their learning. This circle will also help build a sense of pride in their work. You may want to inform students that professional scientists also collaborate with one another to brainstorm, discuss, and review their work.

Share initial models with a partner.* Display **slide J**. Ask students to keep track of similarities and differences between (1) what they think would happen at each point in time for each model and (2) the factors and variables that may have contributed to damage or no damage.

the observable changes, which will provide an opportunity to bring related DCIs from prior grades: grade 4 (energy transfer in collisions), grade 2 (objects pull or push each other when they collide), and the middle school grade band explanation (such as equal force pairs between the two objects in contact). There are phrases in the prompts that ask students to consider related elements of CCCs as well, particularly cause and effect, systems and system models, and stability and change.

7. Establish shared norms.

10 MIN

Materials: *Science Classroom Norms*, science notebook, scissors, tape

Introduce the idea of coming to consensus as a class. Tell students, *Soon, we'll try to come to agreement with all our diagrams*. The purpose of introducing the consensus task before talking about classroom norms is to get students thinking about how difficult it will be to get all members of the learning community to agree and how we want to make sure everyone is included and all voices are heard.

Introduce science classroom norms. Tell students that before the class moves on with further investigations, it is time to set up some norms for how the class wants to work and learn together. You may want to reiterate productive behaviors you witnessed in the first day of Lesson 1 as a way of communicating to students that they were already operating using some positive norms, but they had not yet talked about them.

Display **slide K** and pass out the handout *Science Classroom Norms*. Note: Edit the handout and slide as desired for your classroom.

Remind students that in prior units we have used norms to help develop a productive and respectful learning environment. They are similar to rules but are intended to ensure that all students have a positive learning experience in science class.

The norms on the handout and the slide are a starting point for the class.* It is important to talk through each one with students and ask them to provide an example or paraphrase the norm. The purpose of this is to develop a shared

*** Attending to Equity**

Supporting Emergent Multilinguals: Before students engage in whole-class discussions, it can be helpful to first provide them with the opportunity to work with others—either in pairs, triads, or small groups—on ideas related to their reasoning. These smaller group structures can be especially helpful for emerging multilingual students because they offer students a chance to engage in sensemaking with their peers and also the space to use their linguistic and nonlinguistic resources to express their ideas (and learn from other students' uses of these resources too).

understanding of each norm. Also, provide opportunities for students to clarify a norm, ask for a modification, or develop a new norm. Allow students to write on their handouts if the class decides to change something. Norms are intended to be shared by the students and teacher, so even though a set has been provided, it is just a starting point.

Choose a norm to work on today. Ask students to read through the norms one more time, nominate one norm that may be particularly hard to follow, and suggest a strategy that could help everyone adhere to it. Then, before the students end their conversation, ask them to silently pick one norm from the sheet that they personally will work on today. Give them at least 30 seconds of quiet, individual think-time to make this decision.

Alternate Activity

When setting up learning community norms, students should understand how norms help everyone in the community understand what is expected of them. Here are two approaches to setting up norms:

- Give students a set of norms as a starting point (the default approach written in the learning plan). Share a set of community norms with students and provide space for students to edit or add to the norms if they believe something is missing.
- Co-construct norms with students (the alternate approach). Explain what norms are and why we need them for productive science talk and classroom culture. Have students co-construct norms, first sharing ideas in small groups and then sharing with the whole class. Compile a list of agreed-upon classroom community norms. As the teacher, you can add norms that may be missing from the list. Make sure to explain to students how you think the norm you added is helpful so that they are clear about why you are adding it to the list.

Consider the following questions, which can help you determine which approach is best for your situation:

- Do you want students to participate in co-constructing the norms?
- Do you want the same set of norms for every section of science you teach?
- Do you want to work with your team teachers to establish a shared set of norms for students across all your classes?
- What kinds of consequences will you enforce if students do not follow the norms?

Additional Guidance

Before moving on to the next step, let students take a moment to cut and tape the handout into their notebook (or you can wait until they break from the Scientists Circle and return to their desks). If there are many edits, you may choose to modify the document and reprint it for students before they tape it into their notebooks. It will be important for the norms to appear early in their notebook. Consider taping it to the inside cover of the notebook so that it is easily and often seen by students. Also be sure to have a public place where the norms are posted on the wall for students to reference.

*** Attending to Equity**

Universal Design for Learning: It is important to use this norm-building time to begin to cultivate an equitable learning community that promotes trusting and caring relationships that foster student *engagement*. The norms should remind students to value the diversity of classroom community members and equity in the sensemaking work they will do together this school year. It is critical that the norms support safe and fair participation and interrupt cultural norms or stereotypes that could make science experiences feel uncomfortable to students (e.g., being someone who is not intelligent enough to think like a scientist, who cannot do the relevant math, who cannot share their thinking).

8. Develop initial Consensus Model discussion and related questions. 25 MIN

Materials: *Initial Model: Objects During Collisions*, *Object Interactions During a Collision*, science notebook, markers, Consensus Model for Collisions poster

Share initial models in the Scientists Circle. Display **slide L**. Arrange students around the Consensus Model for Collisions poster.

Say, *Let's start with a model of when the objects in the collision* did *have damage. Let's have a couple of people share their ideas with the class.*

Pick two students with different models from *Initial Model: Objects During Collisions* to come up and show their models to the class. Try to pick examples that look different than the others. Tell students that as their classmates share their models, they should place a small check mark (✓) near what is similar and a question mark (?) near what is different on their own model. Ask students to explain what they think is happening that we can and cannot see between the two objects.

* Strategies for This Initial Ideas Discussion

Accept all reasonable student ideas in this discussion. Revoice students' ideas and use questions, such as *I heard you say_____, is that right?* or *Are you saying ____?* to clarify student thinking. However, do not challenge students beyond their contributions at this point.

Additional Guidance

Use questions to probe students' thinking and get them to articulate each piece of the model. If there are icons like arrows, ask students what they represent. After each presentation, ask students to look at their own model and at the one that was just presented to find similarities and differences between them. If something is repeated several times, emphasize that to the class or ask students to share what was common across the shared models.

Lead a Consensus Discussion to create an initial consensus model. Use the Consensus Model for Collisions poster to incorporate the areas on which we agree. Allow students to share their agreements and disagreements verbally as they naturally arise in the conversation. After you hear a few examples where there is both agreement and controversy, suggest that we should start recording some of these on our poster.

Say, *This poster represents our whole-class thinking. We should feel free to say if it does not represent everyone's thinking so we can figure out what we know and what we are less certain about. We will need to know if we have competing ideas in future lessons so we can figure out what we still need to investigate. Make sure to say something if this does not represent our whole-class thinking.*

Key Ideas

The purpose of this discussion is to capture competing ideas of what causes damage or surprisingly does not cause damage. Students may have various ideas of what causes damage and the factors that can contribute to this damage.

What to look/listen for: Listen for students to reference their models for changes we can and cannot see to determine potential factors for damage. If students are unsure of an idea, record the idea using labels and question marks, as shown in the example model below. Ideas such as energy transfer, pushing, forces, and particle-level changes may be shared by students. At this point, it is OK if only some of these ideas, or more ideas, come up in the class discussion and are represented in the initial consensus model. Be careful not to favorably respond to any one idea over others so as to not give away what might be going on in the phenomenon. The class can return to the model and evaluate their initial competing ideas as they gather more evidence throughout the unit.

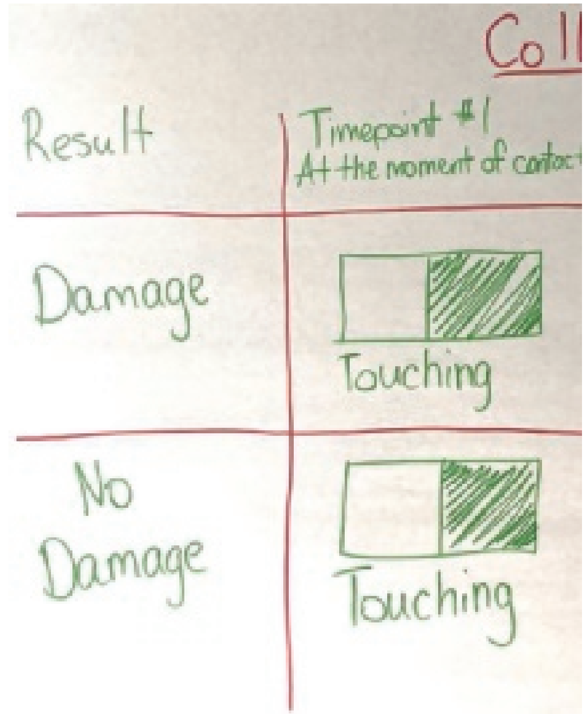
Start by visiting time point 1. Direct students to look at *Initial Model: Objects During Collisions* for initial ideas on what is happening during this time that we can all agree upon as well as competing ideas. Record student ideas on the Consensus Model for Collisions poster. If an idea is not represented by everyone in the class, add a question mark beside the idea. This will cue in future lessons that the class needs to work to develop an understanding of this interaction.

Possible areas of agreement

- The objects are in contact (touching) in both the damage and the no damage case.

Possible areas of disagreement

- any other differences in the objects
- Does the damage occur at time point 1, at time point 2, or at another point in time?



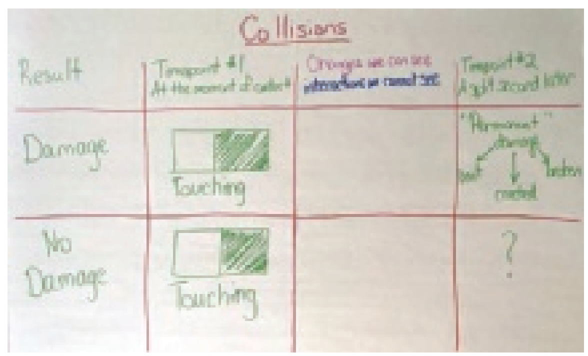
Switch to time point 2. Again direct students to look at their handouts.

Possible areas of agreement

- The damaged item has permanent damage.
- The damaged item is either bent, cracked, or broken.

Possible areas of disagreement

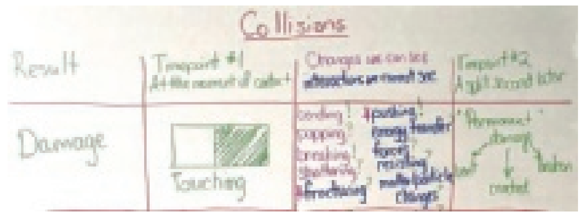
- We aren't sure if there is anything visibly different a split second later for the collision that results in no damage.
- When damage occurs, does damage start a split second after contact or bit before or a bit later?



Shift to the column labeled "Changes we can see" and "Interactions we cannot see". Start with the students' responses for the changes we can see. Then move to the interactions we cannot see. Use two different colored markers to represent the two different categories of responses. Refer students to *Object Interactions During a Collision* for ideas on what we can all agree upon and areas of disagreement. Have students share out what changes we can see occurring between the two objects. Begin with the collision with the damage box and record student ideas. If students can agree across the class on a change we can see, put an exclamation point or other symbol to indicate that there is a whole-class agreement on this idea. If students do not agree on an idea or it does not represent every student's thinking, add a question mark beside the idea. If students have an idea as something that can be seen as well as cannot be seen, star the idea with the marker used to represent the other category (can be seen vs. cannot be seen) to represent that this idea falls into the two different categories (visible and nonvisible) and will be revisited in later lessons. An example of this can be seen in the chart below. On this chart, fracturing was listed first as an interaction we cannot see AND a change that we can see. A pink star was added next to it to indicate that it falls into both categories.

<table>
<tr>
<td>Potential student responses for changes we see in a collision with damage

bending
popping
breaking
shattering
fracturing (may also be represented by some students as an interaction we cannot see)
pushing or forces (may also be represented by some students as an interaction we cannot see)

</td>
<td>

</td>
</tr>
<tr>
<td>Potential student responses for interactions we cannot see in a collision with damage

fracturing (may also be represented by some students as an interaction we cannot see)
pushing or forces (may also be represented by some students as an interaction we cannot see)
energy transfer or flow
forces
resisting (or other ideas about some sort of internal material response such as stress)
particle-level interactions or changes

</td>
<td></td>
</tr>
</table>

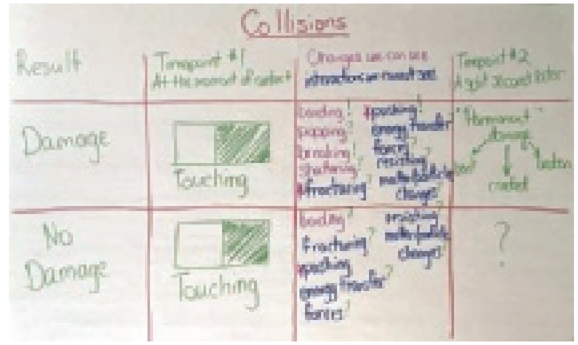
After potential agreements and disagreements have been identified and recorded, move to the remaining empty box that represents a collision without damage.

Potential student responses for changes we see in a collision without damage

- bending

Potential student responses for interactions we cannot see in a collision without damage

- pushing or forces (may also be represented by some students as a change we can see)
- energy transfer or movement
- forces
- resisting (or other ideas about some sort of internal material response such as stress)
- particle-level interactions or changes
- fracturing at a scale smaller than we can see (to account for the idea that there might be damage that we can't see which helps explain why things wear out over time)



Reflect and record questions. Project **slide M**. Take a moment to reflect on this Consensus Model for Collisions poster as a class. Ask students to title a new page in their notebooks "Initial Collision Questions" and record on that page any new questions they have regarding the initial consensus model. We want to make sure to capture these wonderings we have about what is happening during the collision while we still have them fresh in our minds. These questions will be revisited while creating stickies to add to the Driving Question Board on day 3.

Say, *Wow, we've captured a lot of questions. All of these appear to be related to the ideas we were discussing about what was occurring during the collision. Let's take a different perspective now and think about what other variables and factors in the system might influence whether a collision would result in damage or no visible damage from before the objects were even touching.*

9. Determine factors and variables that affect damage. 5 MIN

Materials: science notebook, Factors and Variables poster, markers

Show **slide N**. Have students look back at the Patterns in collisions T-chart in their notebooks.

Create a public record of students' ideas. Display the Factors and Variables poster.

Say, *This will be a record of our initial ideas, and even though we might all agree on some of these being important variables, we don't yet know how important each one is or which variables or factors make the biggest difference, so I want to put a question mark next to each to indicate that as we quickly record a running list of different possibilities you share.*

If students become stuck on wanting to not add a question mark to a particular idea that is shared (e.g., we are all certain that mass is an important factor), ask questions such as these:

- *Is X factor or variable more influential in a collision than Y factor or variable?*
- *So is this factor or variable more important than another factor or variable in a collision?*
- *Would this factor or variable still have as much of an impact on the outcome as this other factor or variable? What if we changed only this one variable instead of the other or vice versa?*

Record student ideas. Students might suggest these ideas:

- speed of the moving object(s)
- size, weight, or mass of the moving object(s)
- shape of the objects
- material those objects are made of
- how hard or soft those objects are
- the angle they hit each other from
- any padding or protective material around either object

At the end of the period, ask students to think more about what factors and variables that are not on our chart might have an affect on the outcome of a collision. Students can ask family, friends, or community about what they think affects damage in a collision if they need more ideas.

It is OK if you do not complete this chart during this class period. It will be revisited at the beginning of day 3.

Additional Guidance

Students may begin to compare collision types A and B. This is fine; however, remind them that we are focusing on the cause of the damage or no damage that is done in the collision. Here are some questions you can use:

- Would it always get damaged like this? What factors could cause this to change whether it is damaged?
- What variables would cause this to get more or less damaged?
- What about the object or the setup might affect the amount of damage?
- If we were to change this object to another object, what would we say makes this object easier or harder to damage?

End of day 2

10. Navigation

3 MIN

Materials: *Science Classroom Norms*, science notebook

Choose a norm to work on today. Display **slide O**. Tell students, *We will spend all day in our Scientists Circle again, working on turning our ideas into questions that we can investigate*. Direct them to look over the Classroom Norms chart again. Ask students to nominate a norm that the class should work on as a group. Take a vote and choose a norm to focus on together today.

Say, *What strategies can we use to stick to this norm together?* Solicit 2-3 student ideas before revising the Factors and Variables poster.

11. Revisit Factors and Variables poster. **7 MIN**

Materials: science notebook, 1-2 index cards, marker, Factors and Variables poster

Project **slide P**. Revisit the Factors and Variables poster with students. Ask if they have identified any other factors that may affect damage in a collision. Record student ideas on the poster.

Write additional questions individually. Project **slide Q**. Pass out 1-2 index cards or sticky notes to each student. Remind them that though we generated questions last time based on what was happening during the collision, they may have new questions about some of these variables and factors from today. Direct students to look back at their Initial Collision Questions notebook page and the Factors and Variables poster. Ask students to use a marker to write on the sticky notes or index cards one or two questions they have developed, one question per card. They should write their questions so they are big and bold. We want to be able to see the questions clearly. Remind students that it will be part of our mission over the next few weeks to try to answer these questions as well as the ones they wrote last time.

12. Driving Question Board and Ideas for Investigations **28 MIN**

Materials: *Initial Model: Objects During Collisions*, *Object Interactions During a Collision*, science notebook, Driving Question Board, Consensus Model for Collisions poster, index cards, tape, chart paper, markers

Start our Driving Question Board (DQB). Before class begins, be sure to have the DQB set up in the room. Place the Consensus Model for Collisions poster near the DQB. Say, *We have been analyzing different types of collisions and the results of those collisions. We have identified possible variables and factors that contribute to damage or no damage, and we want to find out exactly how those collisions cause damage.*

Write the unit question at the top of the DQB: "Why do things sometimes get damaged when they hit each other?" Give students a moment to gather their index cards from the last activity and record any new questions on new index cards they may have related to collisions.

Gather in a Scientists Circle around the DQB. Display **slide R**. Instruct students that when they have their questions ready, they need to bring them and chairs to meet in a Scientists Circle around the DQB. Explain to students how you will create the DQB (also shown on **slide R**):

- The first student reads a question aloud to the class, then posts it on the DQB.
- Students who are listening should raise their hands if they have a question that relates to the question that was just read aloud.
- The first student selects the next student whose hand is raised.
- The second student reads a question, says why or how it relates, and posts it near the question it most relates to on the DQB.
- That student selects the next student.

***Supporting Students in Engaging in Asking Questions and Defining Problems**

If a student forgets to explain why or how their question is linked to someone else's question, press that student to try to talk through their own thinking. This is a key way to emphasize the importance of listening to and building off each other's ideas and to help scaffold student thinking.

If students can't figure out which question to connect theirs to, encourage them to ask the class for help. After an idea is shared, ask the original presenter if there is agreement and why, and then post the question.

If any student has questions that are similar to (or the same as) others that are posted and has

- If another student has shared the same question that you have, try to share a different question that has not been shared.
- We will continue until everyone has at least one question on the DQB.*

Assessment Opportunity

Building towards: 1.B Ask questions that arise from observations of collisions between two objects in order to seek additional information about factors (causes) that might affect the outcome (effect) of such collisions.

What to listen for:

- A variety of open-ended questions (how and why), instead of close-ended questions (yes and no)
- One or more questions about the factors and variables that affect the amount of damage in a collision
- One or more questions about the changes and/or interactions occurring during a collision (between time point 1 and time point 2)

What to do:

- If students are asking mostly closed questions, you can provide a copy of the questions on the DQB and ask them to work on refining three or more of these questions so they become how and why questions that can still also address parts of the original yes or no question. This could be an in-class or home learning assignment. For practice (e.g., exit or entrance ticket) the following two questions can be answered at the end or start of any future lessons:
  - *What questions were raised for us (now or from the end of the last class)?*
  - *How might we investigate one or more of those questions using equipment in our classroom to collect our own data or using data that other people have collected in other places?*
- If students are not asking about the factors and variables that may contribute to damage, have students refer to the Patterns in collisions chart they created in their notebooks and think about how changing one of those factors or variables might impact the severity of the collision. This also could be a recurring home learning assignment for students to continue to discuss with family, friends, and community, as suggested at the end of day 1 of this lesson.
- If students are not asking questions about the changes or interactions occurring between time point 1 and time point 2, have students refer to the initial consensus model and/or *Initial Model: Objects During Collisions* and *Object Interactions During a Collision* to identify areas of uncertainty.

Organize questions into categories. As students share, questions will naturally start clustering into similar parts of the model or similar questions. Once students have finished their sharing, ask them to identify the categories of questions and write these category names near each cluster of questions. To stay on track, save at least 8 minutes of class time for students to think about investigations. See the image that follows for an example of student questions divided into potential categories. If you are short on time, create candidate categories yourself after this lesson, post them, and then share these with students at the start of the next class, asking them to make any suggested modifications to these if they think they don't quite capture the themes that emerged on the board.

An example of a Driving Question Board created using student questions from a pilot classroom is below.

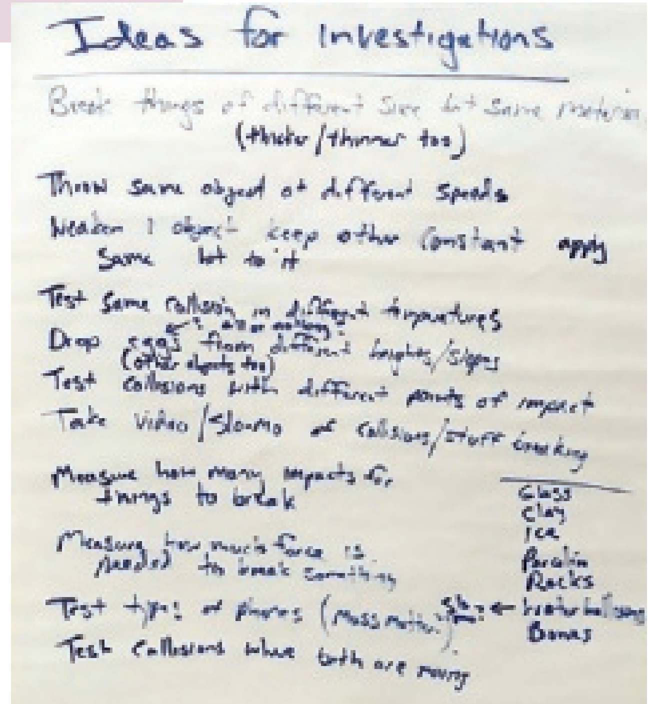
no new ones, have the student place one of their questions on top of the question that is similar so other students can visually see how many of the questions are the same or related. Emphasize that this provides us with evidence of where many people are thinking about similar things.

Stay in a Scientists Circle to brainstorm investigations. Show **slide S**. Read the slide. Give students about five minutes to individually record in their notebooks some ideas for future investigations. As students are doing this, create a new poster titled “Ideas for Investigations and Data We Need.” Put this right next to the DQB.

Tell students that you are going to record their ideas and that you want everyone’s idea to be represented. As students are sharing their ideas, underline repeated statements to keep track of common ideas among students. Emphasize that the list is what we want to do that we think might help us answer our questions and that we may need to add to this list and update our DQB throughout the unit as we go.

Scientists Circle

One way to ensure that all student ideas are shared and get up on the board or poster is to pass a marker to the first person nearest you in the circle. The student with the marker should share one idea. Write it on the board or poster. Once that student sees that you have almost finished writing it, that student should pass the marker to the next student. The second student then shares an idea. If the idea is on the poster already, the student should say which idea is similar and how it is similar. Put a tally mark next to that idea. In this way, the marker is passed all around the circle and all students have a chance to have their thinking represented on this poster. Remind students that if they have additional ideas that don't end up on the poster, they should jot them down now and then raise a hand to share only after the marker makes it all the way around the circle.



13. Navigate to next lesson.

2 MIN

Materials: None

Forecast that we will investigate our questions. Display **slide T**. Say, *Wow. We have accomplished so much. We now have a broad mission to accomplish as a class. That is thanks to all the questions you shared and how you connected them together. These questions really represent what it is we hope to be able to figure out. And we have a lot of ideas for investigations we could do to try to figure this all out. I am very excited for us to be able to get started on investigating all of this. Let's plan to start exploring some of those questions and ideas in our next lesson.*

14. Revisiting Norms

3 MIN

Materials: *Science Classroom Norms*, science notebook

Debrief how we did with our focal norm. Display **slide U**. Have students turn and talk and share how they did with the norm they selected. Ask students, *How did the norms help us talk together and come up with some ideas of what we think is happening*? Allow a few students to share and tell students they will continue to work on the norms.

15. Add to the table of contents.

2 MIN

Materials: science notebook, chart paper, markers

Update the table of contents with students. Say, *But before we start on one of our investigation ideas, let's organize the work we have done so far.* Take any remaining time to have students update their table of contents and page numbering to include references to all the work they have done so far. Develop a sample table of contents with students on chart paper to show one way to name the work they have in their notebooks and reference the related pages it is on. If you run out of time for this today, make sure to do this before the start of the next lesson the next time you meet.

Science Notebook

If this is the first unit of your 8th grade course, you may want to remind students to update their notebooks on days when you have some extra time available. It is recommended that you make time to have students update the table of contents whenever they are adding to their Progress Tracker for the unit. This will happen individually at the end of most lessons and collectively at other key points in the unit. This periodic time for organization helps students look back on the trajectory of their learning journey. For many students, this is a helpful way to support coherence. If you run out of time for this at the end of this class period, it can be moved to the beginning of the next class.

ADDITIONAL LESSON 1 TEACHER GUIDANCE

Supporting Students in Making Connections in ELA

CCSS.ELA-LITERACY.SL.8.1.C Pose questions that connect the ideas of several speakers and respond to others' questions and comments with relevant evidence, observations, and ideas.

When the class is building the Driving Question Board (DQB), if a student forgets to explain why or how their question is linked to someone else's question, press that student to try to talk through their own thinking. This is a key way to emphasize the importance of listening to and building off of each other's ideas and to help scaffold student thinking.

Don't worry if some questions are raised that are not part of topics in this unit. Over time, students will get better and better at forming testable questions within the scope of the driving question. This type of activity gives them practice at doing that.

If students can't figure out which question to connect theirs to, encourage them to ask the class for help. After an idea is shared, ask the original presenter if there is agreement and why, and then post the question.

LESSON 2

What causes changes in the motion and shape of colliding objects?

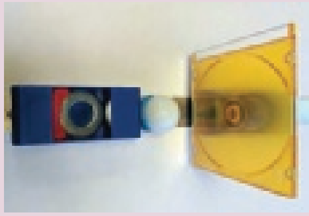
Previous Lesson

We shared our experiences with cell phones breaking and brainstormed related phenomena. We identified factors and variables that can cause some fragile objects to become damaged more than others. We developed a model to describe what is happening to the objects in a collision. We developed questions for our Driving Question Board (DQB) and possible investigations we could do to answer these questions.

This Lesson

Investigation

2 DAYS



We explore colliding objects and record observations about changes in their motion and shape. We analyze slow-motion videos of some of these collisions. We develop a model to represent what we know about energy transfer and forces occurring in collisions when we see changes in motion of objects, shape of objects, or damage to objects.

Next Lesson

We will make a claim about whether all solid objects bend or not when pushed in a collision. We will analyze slow-motion videos, carry out an investigation with a laser and a mirror, and analyze a concrete joint load testing video. We will use these sources of data to argue for whether our original claims are supported or refuted by the evidence

Building Toward NGSS

MS-PS2-1, MS-PS2-2, MS-PS3-1, MS-ETS1-2, MS-ETS1-3, MS-LS1-8

What Students Will Do

2.A Collect data on changes in the motion and shape of colliding objects that serve as the basis for evidence that energy transfer occurs during the collision and that there are forces between colliding objects.

2.B Construct an argument supported by empirical evidence and scientific reasoning to support a model showing that changes in motion of colliding objects (connected to subsystems) result from energy transfer between them (cause) and changes in the shape of those objects result from force(s) between them (cause).

What Students Will Figure Out

- A collision can cause the objects involved to change motion and/or change shape.
- Energy transfer occurs during a collision.
- There is a force(s) between objects when they make contact during a collision.

Lesson 2 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	4 min	**NAVIGATION** Reinforce our shared definition of *collision*, recall the investigations proposed at the end of Lesson 1, and brainstorm what sorts of observations we want to take in a collision investigation.	A	safety goggles, Different Collisions poster from Lesson 1
2	13 min	**INVESTIGATE DROPPING AND BREAKING** Explore what happens to objects during a collision by dropping rigid objects on fragile but inexpensive targets and making observations.	B	safety goggles, Dropping and Breaking Lab
3	10 min	**DISCUSS DESIGN CHALLENGES: DROPPING AND BREAKING** Discuss challenges associated with making observations of collisions from dropping objects on fragile targets.	C-F	*Exploring Horizontal Collisions*
4	13 min	**EXPLORE HORIZONTAL COLLISIONS** Record data about the motion and shape of objects in the system before and during collisions.	G	*Exploring Horizontal Collisions*, safety goggles, Exploring Horizontal Collisions Lab
5	5 min	**NAVIGATION** Students use evidence from investigations to discuss patterns in motion and shape changes.	H	
				End of day 1
6	10 min	**NAVIGATION: PROBLEMATIZING** Motivate the need for a closer examination of what's happening to the motion and shape of objects during collisions.	I	
7	10 min	**MAKE OBSERVATIONS OF SLOW-MOTION VIDEOS** Analyze slow-motion videos for evidence of bending in a collision. Record observations and determine if observations support or refute the claims made.	J-M	computer, projector, slow motion videos (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**)
8	20 min	**CONSENSUS DISCUSSION AND PROGRESS TRACKER UPDATE** Come to consensus about what causes changes in motion and shape of colliding objects and update Progress Trackers.	N	chart paper, markers
9	5 min	**BRAINSTORM MATERIALS TO TEST** Raise questions as to whether the shape of all objects changes during a collision.	P-Q	
				End of day 2

Part	Duration	Summary	Slide	Materials
		SCIENCE LITERACY ROUTINE Upon completion of Lesson 2, students are ready to read Student Reader Collection 1 and then respond to the writing exercise.		Student Reader Collection 1: *Collisions*

Lesson 1 • Materials List

	per student	per group	per class
Dropping and Breaking Lab materials		• 5 dry rice noodles • 1 CD case (plus more in reserve) • 1 piece of sugar glass (or 2 soda crackers) • 2 bricks or heavy books • 1 golf ball • 1 tennis ball • 1 marble	
Exploring Horizontal Collisions Lab materials		• (optional) 1 phone or tablet with slow-motion video capability for student-made slow-motion videos	• 8 stations built from 8 aluminum bar tracks (3 ft. x 1.5 in. × ⅛ in. each) • 8 1-ft. pieces of painters tape • 16 carts • 4 metal rings and mounting screws that come with the carts • 4 rubber stoppers that come with the carts • 4 clay balls (1- to 2-in. diameter) • 3 quarter-sized pieces of sticky putty for mounting materials to each cart • 2 golf balls • 2 CD cases • 24 washers

	per student	per group	per class
Lesson materials **Student Procedure Guide** **Student Work Pages**	• science notebook • safety goggles • *Exploring Horizontal Collisions*		• Different Collisions poster from Lesson 1 • computer • projector • videos (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**) • chart paper • markers

Online Resources

Materials preparation (50 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Day 1 (40 minutes)

Dropping and Breaking Lab

- **Group size**: 4-5 students
- **Setup**: Gather materials for 6 stations.
- **Materials at each station**
  - 5 dry rice noodles
  - 2 bricks or 2 heavy books
  - 1 golf ball
  - 1 tennis ball
  - 1 marble
  - 1 piece of sugar glass or 2 soda crackers
  - 1 CD or DVD case (It is anticipated that the cases may get damaged at this station. That is by design. Have extra cases available to swap in when this happens.)
- **Materials to make sugar glass**
  - 1 1-lb bag of Arcor Crystal Mints (note: You may also use Matlow's Hard Mint Candy or Jolly Ranchers, however, melting times may vary slightly.)
  - 1 6-cavity silicone soap mold measuring approximately 3″ x 2″ x 1″ per cavity
  - 1 cookie sheet
  - 1 cooling rack
  - 1 can of nonstick cooking spray
  - 1 resealable, plastic storage bag, gallon size
  - an electric, gas, or toaster oven

- 1 roll of wax paper
- paper towels
- 2 oven mitts or hot pads
- 1 splash goggles

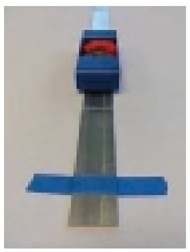
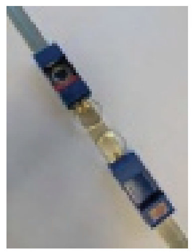
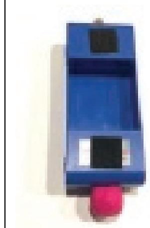
- **Directions for making sugar glas**s
  - See *Making Sugar Glass* and the supporting video for information about preparing sugar glass. (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)
  - Store sugar glass between sheets of wax paper and seal in a resealable, plastic storage bag until ready to use.
- **Safety:**
  - Wear safety goggles or glasses during the setup, hands-on, and take-down segments of the activity.
  - Never eat any food items used in a lab activity.
  - Make sure all other fragile items are removed from the test area.
  - Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
  - Broken pieces of sugar glass may be sharp and should be handled carefully.
  - Immediately pick up any items dropped on the floor so they do not become a slip/fall hazard.
  - Follow your teacher's instructions for disposing of waste materials. Wash your hands with soap and water immediately after completing this activity.
- **Disposal:** Broken dry rice noodles, soda crackers, and sugar glass can be disposed of in trash. Broken pieces of sugar glass may be sharp and should be wrapped in something such as paper towels or newspaper to avoid tearing trash bags or cutting someone handling trash bags. It is anticipated that CD or DVD cases may get damaged in this lab. That is by design. They can be recycled. All the other materials can be stored and reused from year to year.

Exploring Horizontal Collisions Lab

- **Group size:** 3-5 students
- **Setup:** Create 8 stations, two of each of four types indicated below. Groups will rotate through at least three stations to test collisions using different objects at those stations.
- **Materials split equally across all stations (see step 1 below)**
  - 8 aluminum bar tracks (3 ft. x 1.5 in. x ⅛ in.)
  - 8 ft. painters tape
  - 16 carts
  - 24 washers (1.5-in. diameter)
  - 24 quarter-sized piece of mounting putty for sticking materials to or washers within carts
- **Materials to split up across different stations (see steps 2-4 below)**
  - 4 metal rings and mounting screws that come with the carts
  - 4 rubber stoppers that come with the carts

- 4 clay balls (1- to 2-in. diameter)
- 2 golf balls

- **Materials to replace as often as damage occurs to them (see step 4 below)**
  - CD or DVD cases. It is anticipated that the cases will get damaged at this station. That is by design. Have extra cases available to swap in when this happens or between groups.
- Follow steps 1-5 below for stations 1-4. Repeat steps 1-5 for stations 5-8.
- **Disposal:** It is anticipated that CD or DVD cases will get damaged in this lab. That is by design. They can be recycled.
- **Storage:** Clay and sticky putty should be stored in air tight containers or ziplock bags. All the other materials can be stored and reused from year to year without special containers for them.

1. At each station, tape down a track to guide the carts during the collision. 	2. At the first station, attach rubber stoppers to the cart screws. 	3. At the second station, attach metal hoops to the cart screws. 	4. At the third station, attach the golf ball and CD case to carts with mounting putty. 	5. At the fourth station, attach a clay ball to the front of each cart. 

Notes for during the lab: There should be two identical stations for each of four collision types. Students will rotate through at least three different stations.

- **Safety**:
  - Wear safety goggles or glasses during the setup, hands-on, and take-down segments of the activity.
  - Never eat any food items used in a lab activity.
  - Make sure all other fragile items are removed from the test area.
  - Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
  - Warn students to keep fingers out of the way when colliding cars, especially when they are holding one car still.
  - Immediately pick up any items dropped on the floor so they do not become a slip/fall hazard.
  - Follow your teacher's instructions for disposing of waste materials. Wash your hands with soap and water immediately after completing this activity.

Day 2 (10 minutes)

Slow-motion collision videos

- Ensure videos are accessible. (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**)

Lesson 2 • Where We Are Going and NOT Going

Where We Are Going

In this lesson, students begin to develop an initial understanding of the cause-and-effect relationships between forces and shape changes of colliding objects and between energy transfer and changes in motion of colliding objects.

Students should notice that the shape of objects changes when the objects are flexible, but they are likely to say that other objects in the collision are not changing shape (they will figure out that they are in future lessons). Students describe what they see in the data by considering whether the effects (changes in shape or motion) are caused by the collision or only correlated with the collision. Students develop an intuitive feel for the idea that more than one force can act on an object when they compare the effects of the collision when the object is held still and when it is not held still.

Students should also leverage prior knowledge that collisions transfer energy as evidenced by changes in the speed of the objects in the system before vs. after the collision. Students may describe motion changes in qualitative terms. For example, they may describe motion changing “quickly” or motion changing “slowly.” Some students may describe changes in motion as also resulting from forces.

We want to help introduce students to two different ways of thinking about the types of interactions occurring between objects during a collision. One is thinking about energy transfers in the system, and the other is thinking about forces applied to objects in the system.

- In the energy perspective, students should recall that energy transfer occurs between objects in a collision and that objects or particles that are moving have kinetic energy. These are ideas that students previously developed at a particle level in *Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)*. Students should also know this from prior grade-band work for PS3.B: *When objects collide, energy can be transferred from one object to another.*
- In the forces perspective, students should recall that there are pushes (force(s)) between the objects in a collision. This is an idea that should have been developed in the K-2 grade band for PS2.B: *When objects touch or collide, they push on one another and can change motion.*

Two modeling conventions are applied to the consensus model in this lesson, based on work students have done in prior units.

- Motion of objects in the system is represented as trails/tails behind an object, whose length is related to its speed. This is a modeling convention that was used in *Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)*.
- Thin, curved arrows from an object or (sub)system to another object or (sub)system are established as a convention for representing such energy transfer in this lesson to provide an opportunity to model forces applied to objects as straight, thick arrows in future lessons in free-body diagrams. Students will have modeled energy transfer using arrows before in the many contexts in physical science, earth science, and life science in multiple prior units from both 6th and 7th grade. Examples include the following:
    - energy transfer through radiation (light) and conduction into and through a cup design
    - energy transfer to Earth’s surface and to the air above through radiation (light), conduction, and convection in the formation of weather systems
    - energy transfer from a system of reactants to food in a flameless heater

- energy transfer into the formation of food molecules in plants through radiation (light) and photosynthesis
- energy transfer through an ecosystem through production and consumption of food in food webs.

Where We Are NOT Going

Wait until Lesson 6 to explicitly connect the ideas of energy transfer and forces together. In Lesson 6 you will establish that when objects collide, the contact forces between them cause energy to be transferred to or from those objects.

Students have prior knowledge of the effects of balanced and unbalanced forces on the motion of an object, but changes in motion due to collision of two objects is new. Do not introduce the term *acceleration*. The NGSS uses the language "change in motion" rather than "acceleration" for middle school students. Do not quantify the rate at which motion changes. No attempt is made at any point in the unit to introduce vector-based thinking about forces to account for changes in motion that are not in one dimension (e.g., along a track). Motion changes outside in systems where the motion isn't bounded in one dimension are outside the boundary of the target performance expectations for the middle school grade band. Students realize that one or more forces exist between colliding objects during contact but may not yet be convinced that the shape of rigid objects changes during a collision. They will investigate this question in Lesson 3.

Don't raise the ideas of force pairs existing between objects when they collide. This is an idea they will develop fully in Lesson 5.

LEARNING PLAN FOR LESSON 2

1. Navigation

4 MIN

Materials: science notebook, safety goggles, Different Collisions poster from Lesson 1

Brainstorm what sorts of things we'd want to look for in a collision. Refer to the Different Collisions poster from Lesson 1 as you say, *Last time, we came up with lots of examples of two objects hitting each other. Here is our poster of these. We decided to refer to all these examples as* collisions, *which is the word scientists use to describe these types of interactions. Since most of our ideas for investigations were to explore some collisions ourselves, let's get ready to start doing that today. I have some materials you will be able to use to test the results of collisions firsthand. Many of those materials are relatively fragile and inexpensive, so it's OK if they get damaged. But, before we just start colliding stuff together, let's take a moment to remind ourselves what sorts of things we wanted to observe more closely in a collision that may or may not result in damage.*

Discuss initial ideas. Project **slide A**. Give students a couple of minutes to talk with a partner. Then ask students to share a few ideas. Listen for ideas such as these:

- *Observing collisions in slow motion might help us see what's happening.*
- *Look up close to try to see what is happening with the materials, both when they break and when they don't.*
- *Make note of how the material behaves in those situations and any changes we see happening to it.*
- *Compare the objects before and after the collision.*

Take safety precautions. Say, *So although there is a "before" and "after" for a collison, and it's easy to compare these, one big area of interest for us is to try to see what is going on during the collision itself. Trying to see what is going on up close sounds like one thing we are going to want to try to do. But, knowing that the objects might get damaged and if that happens, pieces may get broken off in some of the collisions, what is one big safety precaution we are all going to want to take during our attempts to study collisions up close?*

Listen for safety suggestions that include wearing goggles and not getting too close.

Safety Precautions

For this investigation, as well as for all future collision investigations in this unit, students should follow these safety guidelines:

- Wear safety goggles or glasses during the setup, hands-on, and take-down segments of the activity.
- Never eat any food items used in a lab activity.
- Make sure all other fragile items are removed from the test area.
- Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
- Warn students to keep fingers out of the way when colliding cars, especially when they are holding one car still.
- Immediately pick up any items dropped on the floor so they do not become a slip/fall hazard.
- Follow your teacher's instructions for disposing of waste materials. Wash your hands with soap and water immediately after completing this activity.

2. Investigate dropping and breaking.

13 MIN

Materials: Dropping and Breaking Lab, science notebook, safety goggles

Demonstrate one possible collision setup. Don't actually drop any objects in this demonstration step. The intent here is to just give students a few ideas to get them started. Gather students around a demonstration area to show one of the ways groups might set up a collision to try. Say, *Here are just a few examples of the kinds of things you might try. Some groups might try to suspend a rice noodle between two books and drop a golf ball on the noodles to see what happens. Others might place a soda cracker directly on the table and drop a tennis ball on it. But these are all vertical drops. You could try collisions from a different direction too.*

Remind students about safety. Say, *In any case you test you will want to take careful observations about what is happening during the collision. That is going to require you to watch the point of contact closely. Let's remind ourselves of important safety guidelines we will need to follow in every collision case we test.*

Safety Precautions

- **Students should wear safety goggles** in case broken pieces of objects are ejected during collisions.
- Students should keep track of tennis balls, golf balls, and marbles so they don't fly away into other groups.
- Students should not drop any object from higher than an arm's length in front of them onto the table top (about 2 feet).

***Attending to Equity**
Universal Design for Learning: Recording observations with words may be challenging for students. Encourage all students to use words and/or drawings when *representing* and recording their investigation setup and observations. Student drawings of broken things can be elevated as class artifacts that clarify different kinds of damage seen in collisions. To help students record observations in their notebooks, have them make a T-chart with the

Prepare to record data in notebooks. Encourage students to describe their tests and record what happens in a format that makes sense to them and to think about what kind of data they need to collect and why. There will likely be many challenges associated with making careful observations, so suggest to students that they record those challenges along with any new questions that come to mind as they work.*

Carry out station investigations. Show **slide B**. Assign students to groups and initial stations. Keep track of time, reminding students to try multiple collisions. Students should be able to complete three collisions in the time allotted.*

3. Discuss design challenges: dropping and breaking. 10 MIN

Materials: science notebook, *Exploring Horizontal Collisions*

Debrief dropping and breaking. Ask students to refer to what they recorded in their notebooks during the *Dropping and Breaking Lab* as you discuss their related observations, challenges, and questions.

Say, *As groups were working, I noticed a lot of us are using different words to describe permanent shape changes to the fragile things in our investigations. Let's add the word* damage *to our Word Wall. It might also be helpful for us to show the different kinds of damage we are seeing.* Using students' own words to describe damage (e.g., nicked, bent, cracked, broken into pieces) and input from students, draw diagrams on the Word Wall to show different degrees of damage. Emphasize that all of these involved shape change.*

Discuss investigation design challenges. Project **slide C**. Give groups 2 minutes to discuss the questions on the slide:

- What did you notice about the motion or shape of colliding objects?
- What challenges did you face?
- How could we study collisions more easily?

Then lead a whole-class discussion to identify similarities and differences in observations about changes in motion or shape, challenges faced, and new questions that emerged.*

Elicit observations about changes in motion and shape of colliding objects. Say, *It sounds like in some cases we noticed changes in both the* ***motion*** *and the* ***shape*** *of colliding objects. This may be something we want to investigate further, but let's identify any challenges we encountered testing collisions the way that we just did.*

Elicit challenges students faced in the previous investigation design. Say, *Share the challenges you experienced in conducting the investigations and making observations with the way we tried to collide objects together in this previous investigation.* Listen for ideas such as these:

- Dropping an object from a higher height makes it harder to hit the target (we miss it).
- The targets bounced.
- It was hard to keep track of the ball or keep it on track.
- It was hard to control the speed of the fall (the speed of collision).
- It was hard to aim the ball so it hit the target in a predictable spot.

title "Observing Collisions" and these column headings:

- Descriptions of collisions
- Challenges or questions

***Supporting Students in Engaging in Planning and Carrying Out Investigations**
As students work, ask, *what kind of data is your group collecting and what question do you think it will help answer?* Additionally, ask them to tell you why it might be important to collect data from different collision scenarios. Students should recognize that collisions in the real world happen in many different ways, and to make sense of what happens during collisions will require a variety of lines of evidence from varied scenarios. Both of these will help prepare them for a second, more focused and controlled investigation in the later part of the lesson.

***Attending to Equity**
Universal Design for Learning: Encourage students to contribute ideas for visual *representations* or to share and display on the class Word Wall their own drawings they made from the previous investigation.
Emergent Multilingual Learners: Using multiple words and images to clarify what is meant by *damage* supports all students and particularly emergent multilinguals. If students are

- It was hard to see what happened to the surface of the fragile object at the moment of contact between objects.
- Collisions happen too fast to make good observations.

Say, *Publicly sharing and identifying the challenges we had with collecting data in an investigation is an important practice in engineering and science as it can help the scientific community refine what they do in their next investigation and how they go about doing it. Let's keep that in mind as an important norm for planning and carrying out investigations. Let's use it to guide revisions for our next round of collision investigations as well as other phenomena that we design investigations for later in the year.*

Discuss what might need to be different about the lab design. Say, *It sounds like it would be really helpful if we could control this collision somehow and keep track of how motion and shape are changing. The things I heard were . . . .* Write ideas on the board and have students agree that we need to

- control the speed of the objects in the collision better,
- control where the moving object hits the target,
- look more closely at the surfaces of colliding objects at the time of the collision, and
- keep the moving object from flying off after the collision.

Assessment Opportunity

Building towards: 2.A Collect data on changes in the motion and shape of colliding objects within a system that serve as the basis for evidence that energy transfer occurs during the collision and that there are forces between colliding objects.

What to look/listen for: Listen for students to suggest ways to control the collisions they observe. For example, they are likely to suggest that they want to see how the materials themselves are changing during the time the objects are in contact with each other. They may also suggest ways to control the motion and speed of objects in collisions, such as a way to target or line up the objects to ensure that they will collide after one or both are put into motion. Students may also suggest the use of slow-motion video or zoomed-in images of the moment of collision.

What to do: To elicit ideas for making better observations during collisions, ask students to think about what should be different about their experimental design. If students still don't have a lot of ideas, add an optional exit ticket at the end of day 1 that asks students to reflect on what about the new setup in the *Exploring Horizontal Collisions Lab* helped address some of the challenges they raised at the end of the *Dropping and Breaking Lab* and/or what about the new setup allowed them to make the kinds of observations they were not able to make as easily before.

Say, *I think we can do some things to control for many of these variables in our next round of collision investigations. I have some equipment we can use that I think might help address some of the challenges you raised. Let's consider how the available equipment could be used to help address those challenges.*

Project **slide D**. Say, *In this image putty was used to attach a golf ball to a cart and it was also used to attach a CD case to a second cart. Notice that both carts are also on a track. This is just one sample of two different kinds of things we could collide together. We could swap in other objects and still attach them to carts using putty.* Discuss the question on the slide as a class.

comfortable, ask them to share words from their home language and look for similarities if possible. For example, in Spanish, a damaged thing is *dañado(a)* and in French it is *endommagé*.

Supporting Students in Developing and Using Scale, Proportion, and Quantity

During the discussion in this section, students should recognize that the real-time data they collect do not provide enough information to make sense of what's happening during a collision. Students are likely to quickly suggest using slow-motion video to better see objects at the moment of impact during a collision. Some students may also suggest zooming in on the objects at the moment of collision, and this is a worthwhile endeavor if they are using phones or cameras in this activity. If a few students take and enlarge photos of colliding objects, taking a minute to project the photos for the class will show their ideas add value to collective understanding.

Suggested prompt	Sample student responses
How would investigating collisions using this sort of setup help us address some of the challenges we encountered in the previous investigation?	*This would allow us to control where the ball hits the target.* *It could help keep the ball from flying off after the collision.* *It will keep everything in a more controlled space.*

Define the system of objects that will be involved in the collision. Say, *It seems like we have ideas about better ways to collect observations during a collision, but since there are different objects in the new system that we are going to use to carry out a collision, let's think about one example of two objects we can collide together within this system. We could collide a golf ball with a CD case if we attached each to their own cart and ran one into the other. In this example, where would we expect the point of contact in the collision to occur?*

Students will say the point of contact will occur where the golf ball and CD case touch each other.

Say, *OK, so even though the golf ball is attached to one cart and is part of that subsystem and the CD case is attached to another cart and is part of that subsystem, the point of interaction we are really interested in studying within the entire system is just between the two objects we identified at first: the golf ball and CD case. Defining what parts, objects, or subsystems within a larger system we are wanting to study the interactions between is an important part of systems thinking that we should keep thinking about going forward in all our investigations and models we develop.**

Turn and talk. Project **slide E**. Ask, *When the objects that are part of the two subsystems make contact during a collision, what sort of changes do you think you might observe in those objects or in the subsystems they are attached to?* Ask students to share a few responses and listen for ideas about whether the motion, the shape, or both motion and shape will change during a collision. For example, students might say that the cart subsystems will bounce backwards or stop, the CD case will wiggle or crack, or the putty will be squished more or less.

Demonstrate controlling collisions with carts. Distribute *Exploring Horizontal Collisions*. Project **slide F**. Have students write the investigation question, What happens to the motion and shape of the objects (and the subsystems they are part of) when they collide?, on the top of their handout as described on the slide.

Prepare for data collection. Say, *The data table provided has space for you to keep track of what is happening to two separate things for two different objects in the system, which is a lot for one person to pay attention to. Turn to your partners and take ten seconds to decide who is keeping track of changes in motion and shape for objects that are part of subsystem 1 and who is keeping track of changes in motion and shape for objects that are part of subsystem 2.*

Demonstrate how to conduct the investigation. Say, *I can use this setup to make the different subsystems collide by running the carts into each other like this (show a crash).* Ask, *What, if anything, did you notice during the collision about changes in the motion or shape of the objects?* Hear a few responses.

Say, *What about the surface of that CD case during the collision? What happens to it? Does it bend or break? Can it bend and not break? What are some tools we could use to help us see what is happening right at the moment two objects make contact and immediately afterward? Are there any technologies we could use to help us see what is happening to the objects that make contact with each other during that really brief event?*

Listen for answers such as

- slow down the speed of the objects before they collide or just push them slowly together instead of crashing them into each other,

Supporting Students in Developing and Using Systems and System Models

Referring to the objects in this collision as being part of subsystems primes students for developing models for free-body force diagrams (subsystems) in Lesson 5. Students also have prior experience describing energy transfers between systems in *Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)* and *Unit 7.2: How can we help people design a flameless heater? (Homemade Heater Unit)* when they describe and model energy transfers in the form of heat and particle motion once they recognized that those systems are made of many different, individual parts interacting together (e.g., molecules colliding, atoms in reactant molecules rearranging). They will leverage this thinking in Lesson 8. This system framing in this lesson primes students for making particle-level connections later in Lesson 8 to account for energy transfer to the surroundings via friction and air resistance.

- try to take a photo of it as it happens and zoom in, and use a slow-motion camera or
- use slow-motion video someone else collected.

Encourage students to pursue any ideas that they have technology to support.

Alternate Activity

If students have access to slow-motion cameras in their phones or tablets, encourage one member of the group to capture such recordings as well. If students don't have access to this technology, tell the class that you will pull together some slow-motion videos of these objects colliding for the whole class to analyze together next time.

4. Explore horizontal collisions. 13 MIN

Materials: Exploring Horizontal Collisions Lab, science notebook, *Exploring Horizontal Collisions*, safety goggles

Explain organization of data collection. Refer students to *Exploring Horizontal Collisions*. Point out that each row is for each different combination of objects they collide together. Students should have the freedom to choose whether to put both carts in motion or hold one steady and should clearly mark that they did so in the column on *Exploring Horizontal Collisions* that asks "Was there a change in motion? (yes/no)." If they hold one cart in place then they write "no (held in place) for one cart."

Project **slide G** and tell students they will have three minutes at each station. Explain that if their group misses a station or are uncertain of the results and don't have time to repeat the investigation at that particular station, they can fill in the corresponding cells of their data table with question marks.

Ask students to collect data for at least three stations. Assign students to work in groups, each at a different starting station. Signal the groups to rotate to a new station every three minutes. This should allow students enough time to get to at least 3 stations. Students should record data on their handout and add their handout to their science notebook when they are done.*

*** Supporting Students in Engaging in Planning and Carrying Out Investigations**
Since it is sometimes easier to see deformation when the carts are more massive, students may use washers to add additional mass to the carts. If they decide to do this, the washer(s) can be held in place with clay. Students should make note of anything added to their system.

Alternate Activity

Optional: Students collect their own video. If students will collect their own slow-motion video, they first may need a moment to look up how to operate the slow-motion video function of their phones or tablets. The primary focus of this activity, though, should not be on students recording slow-motion video. Proceed with this option only if students suggest the idea and the technology is available and easily accessed in the classroom. Remember that you will show the entire class slow-motion video of some of these collisions later in this lesson.

5. Navigation

5 MIN

Materials: science notebook

Identify patterns in data related to changes in motion and shape. Say, *Take a moment to summarize what you figured out about our question that motivated our investigation.* Project **slide H**. Give students the remaining time to record their responses to the question:

- What happens to the motion and shape of the objects (and the subsystems they are part of) when they collide?

If time is short, assign this for home learning.

End of day 1

6. Navigation: Problematizing

10 MIN

Materials: science notebook

Identify patterns in data related to changes in motion and shape. Display **slide I**. Say, *Last time you carried out an investigation to try to figure out what happens to the motion and shape of the objects (and the subsystems they are part of) when they collide.*

Give students a minute to review what they wrote last time in the notebooks. Then have students share the summaries of their observations as a whole class, starting with observations related to changes in motion.

Suggested prompts	Sample student responses
Tell me about the patterns you noticed in the data you recorded in the column "Was there a change in motion?" What did you see?	• *In many cases we saw a change in motion.* • *Sometimes motion didn't change, like when we held one of the carts in place.* • *Sometimes there were changes for both colliding objects, and sometimes the changes were only for one object.*
How many times did you see the motion change and how many times did you see the motion stay the same?	*Answers will vary, but students should report more data showing changing motion than motion staying the same.*
Do you notice any patterns? What were the conditions when the motion changed? *What were the conditions when the motion didn't change?*	• *In every collision, the motion of at least one of the objects changed.* • *In every collision where we didn't hold something still, the motion of both objects changed.* • *The only time the motion of an object didn't change was when we were holding the object still.*

Now have students share the summaries of their observations related to changes in shape. Listen for these ideas:

- With bendable things, we easily saw the shape change during a collision.
- We aren't sure if we would see a shape change with more rigid objects like metal.

Suggested prompts	Sample student responses
Show of hands: How many of you saw changes in shape during collisions?	*Most students should raise their hand.*
Did you always see changes in shape?	*No.*
Did we ever see changes in shape when we held an object still?	*Yes.*

Additional Guidance

Students have been using several terms for shape change, such as *bending* or *squishing*, in this lesson. In the next lesson, the word *deformation* will be introduced and will be used to describe any bending or shape changes in an object.

Say, *So for some objects we are claiming it was easy to see evidence of a shape change. But for other objects we didn't see any evidence of their shape changing. But a lack of evidence doesn't necessarily mean something didn't happen. Sometimes a lack of evidence is due to an inability to measure what we are trying to detect. What are some challenges you encountered with trying to see if the shape of the objects changed during that brief moment that they made contact with each other?*

Accept all responses. Students are most likely to say that the moment of contact happens really fast.

Ask students to consider what additional sources of evidence could help us see if shape changes in the objects that are colliding are occurring during that brief moment of contact. Listen for students to suggest that we would need video of the collision from a slow-motion or high-speed camera.

Say, *I've pooled together slow-motion videos of collisions for us to analyze in order to investigate this question further. Let's get ready to collect some observations from these data sources.*

7. Make observations of slow-motion videos. 10 MIN

Materials: science notebook, computer, projector, videos (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**)

Explain video observation procedures. Project **slide J**. Explain the objects involved in the three different collisions that will be shown in the videos. Give students a minute to create a T-chart for recording observations in their notebooks as shown on the slide. Explain that each video will be played twice. The first time it is played, students should pay attention to what is occuring. During the second viewing, students should record observations.

Play videos and record observations. Project **slide K**. Check that the computer sound is turned off before playing the videos. Play video 1 in its entirety twice. Instruct students to watch the video the first time and to record observations in science notebooks during the second viewing. Continue this process with **slides L** and **M** and video 2 and video 3. (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**)

After showing the 3 videos, say, *Bring your notebooks and let's meet in the Scientists Circle to share our thinking about the changes we are seeing when objects are in contact with each other during a collision.*

8. Consensus Discussion and Progress Tracker Update

20 MIN

Materials: science notebook, chart paper, markers

Come to consensus. Say, *Earlier we found evidence for motion and shape changes in some collisions. When we analyze slow-motion video from collisions, we find further evidence that those changes are happening gradually during the time the colliding systems were in contact with each other. Let's consider what could be causing both of these types of changes.*

Develop cause-effect statements. Project **slide N**. Say, *As we try to figure out what's happening at the moment of impact in a collision, it might be helpful if we could name the causes for each of the effects we are seeing. Individually, think of one of the collision scenarios you investigated and use the prompts on the slide to organize your thoughts about what you think might be causing changes in motion. Then think of one of the collision scenarios where you saw evidence of a shape change. Use the prompts on the slide to organize your thoughts about what you think might be causing changes in shape.*

When objects/systems collide, ____________________, which results in a <u>change in motion</u>.
(cause) ***(effect)***

When objects/systems collide, ____________________, which results in a <u>changes in shape</u>.
(cause) ***(effect)***

If students are struggling to get started, model completing a cause-effect statement using an example that leverages prior knowledge. For example say, *In the weather and climate unit you learned about what happens when two different air masses interact. Let's write a cause-effect statement describing what you figured out about interactions between warm and cold air masses.*

- *When a warm, humid air mass moves toward a cold air mass, <u>the warm air slides over the cold air</u>* (cause)*, and this results in <u>the formation of precipitation like fog</u>, <u>rain</u>, <u>or snow</u>* (effect).

Give students time to think and attempt two cause-effect statements on their own, one for each of collision outcomes: motion changes and shape changes.*

*** Supporting Students in Developing and Using Cause and Effect**

Cause and effect is a focal crosscutting concept in a later unit, *Unit 8.3: How can a magnet move another object without touching it? (Magnets Unit)*; however, in this unit students will gain experience with scaffolds and sentence frames that help them to organize their thinking about mechanistic explanations for phenomena. The purpose of sentence frames is to highlight and make salient the importance of this crosscutting concept for students. In this instance, the sentence frames are designed to help students articulate their observations and potential causes for the effects they observe.

Assessment Opportunity

Building towards: 2.B.1 Construct an argument supported by empirical evidence and scientific reasoning to support a model showing that changes in motion of colliding objects (connected to subsystems) result from energy transfer between them (cause) and changes in the shape of those objects result from force(s) between them (cause).

What to look/listen for: Students making arguments that leverage prior knowledge about changes in kinetic energy, energy transfer, and/or forces in the initial cause-and-effect statements they make. It's OK if students reference only one of these rather than all of them.

What to do: If students struggle with identifying any causes, model the completion of a cause-and-effect statement using understanding from a previous unit. An example from the *Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit)* unit is provided in the Learning Plan. Collect and review students' Progress Trackers at the end of day 2 to see if students are referencing ideas related to kinetic energy, energy transfer, or forces that they may not have mentioned here.

Turn and talk. Give students two minutes to share their ideas with a partner, then hear ideas from 2-3 groups. These are sample student responses:

- *When objects collide, energy is transferred from one object to another, and we observe changes in their motion.*
- *When objects collide, one or more forces push on one or more objects, and we observe changes in shape.*

Use this conversation as an opportunity to connect back to previous units' discussions of energy so students can connect these ideas to prior science ideas they've already figured out around energy. Take the time to have students realize that while they have been talking about energy transfers across the years at vastly different scales, they have always been talking about the same type of phenomenon: energy transfers into or out of systems.*

Additional Guidance

Students will have modeled energy transfer using arrows before in the many contexts in physical science, earth science, and life science in multiple prior units from both 6th and 7th grade. Examples include the following:

- energy transfer through radiation (light) and conduction into and through a cup design
- energy transfer to Earth's surface and to the air above through radiation (light), conduction, and convection in the formation of small-scale weather systems and large-scale air masses
- energy transfer from movement of plates along a plate boundary into the displaced water that produces a tsunami, which in turn is transferred to the shore through the propagation of those waves across the ocean
- energy transfer from a system of reactants to food in a flameless heater
- energy transfer into the formation of food molecules in plants through radiation (light) and photosynthesis
- energy transfer through an ecosystem through production and consumption of food in food webs (e.g., the ecosystem where orangutans live)

* Supporting Students in Developing and Using Energy and Matter

Students should recall from their work with marbles in the *Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)* that moving objects and particles have kinetic energy and that collisions transfer energy. So though energy transfer in a system is not a focal crosscutting concept in this lesson, students should be able to describe the energy transfer between two objects in a collision.

* Supporting Students in Engaging in Argument from Evidence

If students argue that motion changes should also be categorized as an effect for the "Force perspective" row, add that too if everyone is in agreement. If there is some uncertainty about that idea, then still add it and put a question mark after it. The lesson assumes that students will see shape changes as stronger evidence of pushing occurring during a collision, rather than motion changes, and that they will be more ready to make that latter connection in later lessons rather than now. The structure of this chart lays the groundwork for making that connection in later lessons.

Suggested prompts	Sample student responses
I think you've talked about energy before in science class. Can we take a moment and think back to 6th and 7th grade and brainstorm different places where you talked about or represented energy like this before?	*We've talked about energy transfer in One-way Mirror Unit, Cup Design Unit, Everest Unit, Homemade Heater Unit, Maple Syrup Unit, Palm Oil Unit.*
Do you see any connections among how energy is represented in the different systems in these units?	*Answers may vary.*
Even though we've used energy thinking to explain very different phenomena related to a cup of liquid warming up, the formation of a cloud or an air mass, heating up food, or where the energy an orangutan needs to live comes from, we have always been talking about energy transfers into or out of systems. What energy transfers do you recall between systems?	*We talked about a chemical reaction system transfering energy to our food system in Homemade Heater Unit.* *We talked about energy transfer from a particle moving fast hitting a particle moving slowly and transferring energy in Cup Design Unit.* *Energy is transferred from the food sources that orangutans eat (fruits) into their bodies when they consume those foods (Palm Oil Unit).* *Additional responses may vary.*

Explicitly talk about energy transfer versus forces way of thinking. If students don't bring up forces, introduce this line of reasoning to bridge from energy transfer thinking to forces using the prompts below.

Suggested prompts	Sample student responses	Follow-up questions
In the Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit) you thought about what happens in collisions between small particles. How did you describe what happened to the energy of each particle in such collisions?	*Moving particles transfer energy into and out of systems during collisions.*	*That sounds like an energy transfer perspective way of thinking.*
Was shape change of the particles something you were considering too?	*No.*	*OK, so let's consider some of the objects we saw change shape in this collision investigation.*
If the CD case was motionless on a table, what would you have to do to it with your hand to change its shape?	*Squeeze it.* *Push on it.* *Poke it.* *Smash it.*	*That sounds like you would have to bring your hand into contact with it and push on it. That sort of thinking is a way of talking about what is happening from a force perspective.*

Say, *We are raising issues about what is happening using ideas about pushing, which is a way of talking about interactions in the system using forces,* ***and*** *we are also describing what is happening to the motion of the objects using ideas about changes in energy, which is a way of talking about energy transfer. Both seem like important ideas we could use to explain what is happening in a collision. And scientists find both are really helpful ways to explain certain types of changes. Sometimes it seems more helpful to describe what is happening using forces, and sometimes it is more helpful to describe what is happening using energy transfer. But each is a different way of thinking about interactions within a system and between systems. Let's clarify what we are talking about with respect to forces and what we are talking about with respect to energy transfer.*

Ask questions to clarify what is meant by pushing and energy transfer and add the words *force* and *energy* to the Word Wall.

Suggested prompts	Sample student responses
When we say "pushing", what are we talking about?	*Forces.*
Forces are a way of explaining certain types of interactions between objects or systems. But so is energy transfer. What are some of the units you completed where you explained phenomena using ideas about energy transfer?	*Cup Design Unit, Storms Unit, Homemade Heater Unit*
What are some ways that energy transferred in, out, or through systems in the types of phenomena you investigated in those units?	*When particles bump into each other, energy is transferred between them in the cup system.*
	Sunlight transfers energy to Earth's surface which transfers it to the air above which causes that air to heat up, expand, and rise.
	Energy was transferred into or out of our heater system/ food system.
When would we say energy transfer is happening in the systems we investigated in this lesson?	*During the collision.*
How is seeing a collision that results in a stationary object speeding up and a previously moving object slowing down evidence of energy transfer occurring in the collision?	*Energy is transferred to the stationary object when it speeds up, and energy is transferred from the moving object when it slows down.*

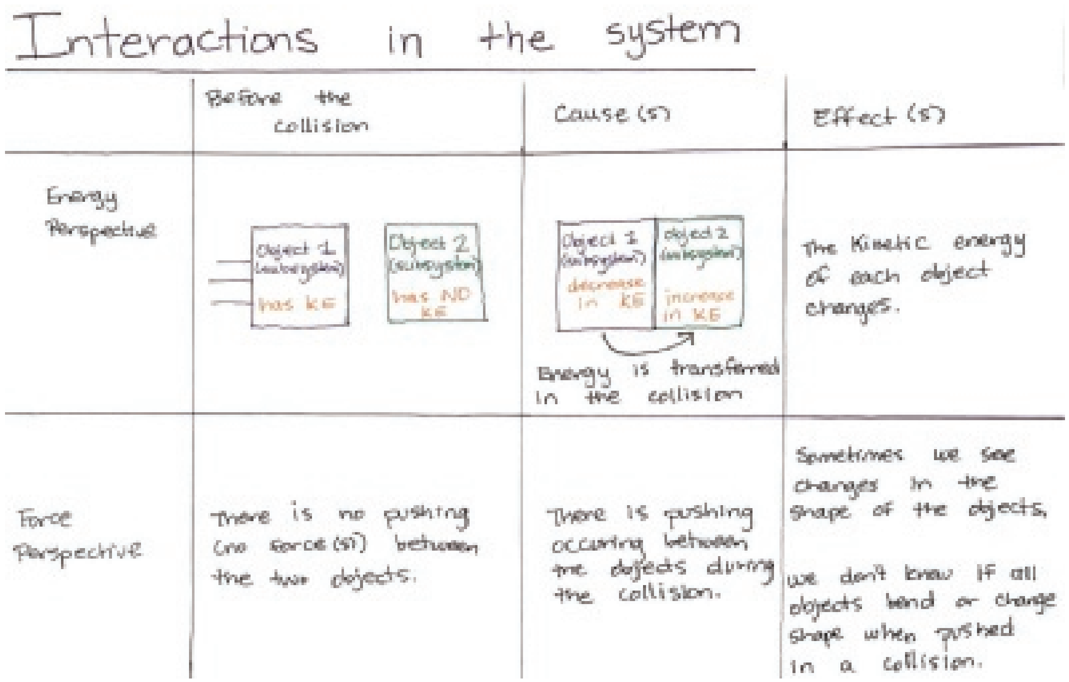
Say, *Let's see if we can come to consensus about how to represent these ideas. Let's use what we already know about energy and forces to show what we think is happening in collisions*. Use questioning to elicit student understanding and record student ideas on chart paper.*

Connect to previous work with kinetic energy in other units. If students start using the term *kinetic energy*, push them to explain their definition and to justify why they feel like this would be appropriate terminology to use here.

If students don't start using the term *kinetic energy*, push them to think about energy transfers from previous units. After we have done some work showing how our current discussion of energy fits in with and builds on previous conversations of energy we have had in middle school, argue that the term *kinetic energy* may be useful for us in this context and that referring to the kinetic energy of moving parts of the system (objects or subsystems) can be a useful way to compare one system to another.

Suggested prompts	Sample student responses
We discussed how energy transfers occur in all sorts of different phenomena. Energy is energy, regardless of the specific context, such as in the Cup Design Unit or Homemade Heater Unit, although sometimes it's helpful to distinguish the form of energy. In the Cup Design Unit what kind of energy were we talking about?	*We talked about particles moving and hitting each other and transferring energy. When they move more, they have more energy. When the particles are moving, they have kinetic energy.*
Is that similar to or different than the energy transfer we are talking about here? Is there anything we figured out about those energy transfers with particles that would be helpful information to use right now?	*Well, before we were working on a scale that we could not see (particles); now we are working at a scale we can see (objects such as balls, phones, and so forth).*
So because we are talking about energy transfers when moving objects collide with each other, the term kinetic energy might be useful for us in this context too. Before a moving object collides with a stationary object, which part of the system has kinetic energy and which part of the system does not?	*The moving object or subsystem has kinetic energy. The stationary object or subsystem does not.*
What is happening to the kinetic energy of each object if their speeds change from the collision?	*If a moving object slows down or stops, its kinetic energy decreases.* *If an object speeds up, its kinetic energy increases.* *If an object that's not moving starts moving, its kinetic energy increases.*
We've used arrows in other units. How might we use them to represent what's happening to the energy in the system during a collision between a moving object and a stationary object that results in the stationary object speeding up?	*We should use an arrow from the moving object to the stationary one to show that these are the parts of the system where the energy is transferring from and to.*
What else do we see occurring in collisions besides changes in motion?	*Shape changes.*
What is causing shape changes?	*Pushing or force(s).*

As you engage students in a Consensus Discussion, capture the class's thinking on chart paper as shown in the images below. Save the chart paper you make to refer to again at the end of Lesson 7 and the start of Lesson 8.*



Project **slide O**. Tell students to add the lesson question to their Progress Trackers: *What causes the changes in motion and changes in shape of colliding objects?* Give students time to individually update their Progress Trackers with what they've figured out so far.

Question	What I figured out
What causes the changes in motion and changes in shape of colliding objects?	• *Forces between objects during a collision cause changes in the shape(s) of the colliding objects.* • *Energy transfers during collisions occur between colliding objects. This can explain changes in the speed of those objects (or the subsystems they are attached to).*

Assessment Opportunity

Building towards: 2.B.2 Construct an argument supported by empirical evidence and scientific reasoning to support a model showing that changes in motion of colliding objects (connected to subsystems) result from energy transfer between them (cause) and changes in the shape of those objects result from force(s) between them (cause).

What to look/listen for: Students making claims that refer to how energy transfer can help account for changes in motion and for how forces can account for changes in shape (students may also mention that forces can account for changes in motion as well).

What to do: If students struggle with identifying the role of forces or energy transfer, leave a sticky note in their Progress Tracker with a prompt or question to push them to continue thinking about how forces or energy transfer could help them explain the changes they observed in the objects when they collided. You may encourage them to respond to this at a later point (e.g., the start of the next lesson). A couple of example prompts are below:

- What else can energy transfer help us explain based on our consensus model from last time?
- What else can force(s) help us explain based on our consensus model from last time?

9. Brainstorm materials to test.

5 MIN

Materials: science notebook

Consider whether shape changes happen in all collisions. Say, *So we've seen shape changes in the collisons we've looked at, where slow-motion video provided the evidence we needed to see that change. And we think that forces in the collision cause this shape change. So is this something that is always happening? Do you think the force from a collision always causes shape changes in the objects that collide, but sometimes we just can't see or detect it?*

Project **slide P**. Take a quick poll in response to this question. Anticipate some controversy around this idea. Say, *It appears we have two competing claims in our classroom. Some of us think that all objects bend or change shape in a collision. And some of us think that not all solid objects bend or change shape in a collision. We are going to need data to support or refute either of these claims. But one challenge in trying to support or refute a claim where we are asking "does this happen in all cases" is that we can't test all cases. So let's brainstorm some types of objects or materials that we know are very rigid that we could test.*

Brainstorm objects and sources of data needed to investigate our question. Project **slide Q**. Have students record their ideas in their science notebooks. If time is short, you may consider asking students to brainstorm objects and sources of data needed to investigate our question as a home-learning assignment. Say, *Let's plan to investigate this question further next time to see if we can collect evidence to support one of these claims and refute the other one.*

ADDITIONAL LESSON 2 TEACHER GUIDANCE

Supporting Students in Making Connections in ELA

CCSS.ELA-LITERACY.W.8.1.B Support claim(s) with logical reasoning and relevant evidence, using accurate, credible sources and demonstrating an understanding of the topic or text.

The above learning goal is the focus of the written cause-effect statements that students produce using evidence from their own investigation on day 2.

SCIENCE LITERACY: READING COLLECTION 1

Collisions

1 **Designing for Collisions**

2 **Describing Collisions**

3 **Modeling Collision Systems**

4 **Beyond Cars and Crashes**

Literacy Objectives

✓ Summarize key points related to collisions.

✓ Organize related details about collisions.

✓ Translate text to visual/graphic representation of ideas.

Literacy Activities

- Read varied text selections related to the topics explored in Lessons 1–2.
- Evaluate the reading selections according to provided prompts and criteria.
- Compare and contrast information gained from reading text with information gained from class investigation.
- Prepare a concept map in response to the reading.

Instructional Resources

Student Reader

Collection 1

Science Literacy Student Reader, Collection 1
"Collisions"

Exercise Page

EP 1

Science Literacy Exercise Page
EP 1

Prerequisite Investigations

Assign the Science Literacy reading and writing exercise *after* class completion of this lesson group:

- Lesson 1: What happens when two things hit each other?
- Lesson 2: What causes changes in the motion and shape of colliding objects?

Standards and Dimensions

NGSS

Disciplinary Core Ideas

PS2.A: Forces and Motion All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared.

ETS1.B: Developing Possible Solutions Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (MS-ETS1-3)

Science and Engineering Practice: Asking Questions and Defining Problems

Crosscutting Concept: Systems and System Models

CCSS

English Language Arts

RST.6-8.2: Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions.

RST.6-8.10: By the end of grade 8, read and comprehend science/technical texts in the grades 6-8 text complexity band independently and proficiently.

Core Vocabulary

Core Vocabulary: Core Vocabulary terms are those that students should learn to use accurately in discussion and in written responses. During facilitation of learning, expose students repeatedly to these terms. However, these terms are not intended for isolated drill or memorization.

collision **force** **kinetic energy**

Language of Instruction: The Language of Instruction consists of additional terms, not considered a part of Core Vocabulary, that you should use when talking about any concepts in this exercise. Students will benefit from your modeling the use of these words without the expectation that students will use or explain the words themselves.

contact forces **design**

frame of reference **model** **velocity**

A Glossary at the end of the Science Literacy Student Reader lists definitions for Core Vocabulary and selected Language of Instruction.

1. Plan ahead.

Determine your pacing to introduce the reading selections, check in with students on their progress, and discuss the reading content and writing exercise. If you are performing Science Literacy as a structured, weekly routine, you might implement a schedule like this:

- Monday: Designate a ten-minute period at the beginning of the week to introduce students to the assignment.
- Wednesday: Plan to touch base briefly with students in the middle of the week to answer questions about the reading, to clarify expectations about the writing exercise, and to help students stay on track.
- Friday: Set aside time at the end of the week to facilitate a discussion about the reading and the writing exercise.

Exercise Page

EP 1

2. Preview the assignment and set expectations. (Monday)

- Let students know they will read independently and then complete a short writing assignment. The reading selection relates to topics they are presently exploring in their Contact Forces unit science investigations.
- The reading and writing will be completed outside of class (unless you have available class time to allocate).
- Preview the reading. Share a short summary of what students can expect.
  - *First, you will read an article describing how automobiles are designed to reduce injury to drivers and passengers and how sports helmets are designed to reduce head injuries.*
  - *Next, you'll take a close look at how an observer's point of view affects the way they describe the motion of themselves and other objects.*
  - *Then, you'll read how scientists and engineers think about and model systems involving collisions.*
  - *Finally, you'll survey collisions in nature—that may or may not involve humans or human-designed objects.*

- Distribute Exercise Page 1. Preview the writing exercise. Share a summary of what students will be expected to deliver. Emphasize that Science Literacy exercises are brief. The focus is on thoughtful quality of a small product, not on the assignment being big and complex.
    - *For this assignment you will be expected to generate a concept map linking together the big ideas in this collection.*
- Remind students of helpful strategies they can employ during independent reading. Offer the following advice:
    - *The reading should take approximately 30 minutes to complete.* (Encourage students to break reading into smaller sections over multiple short sittings if their attention wanders.)
    - *A good reading strategy is to scan through the collection first to see the titles, section headers, graphics, and images to see what the selections are going to be about before fully reading.*
    - *Next, "cold read" the selections without yet thinking about the writing assignment that will follow.*
    - *Then, carefully read the Exercise Page to understand the expectations for the writing part of the assignment.*
    - *Revisit the reading selections to complete the writing exercise.*
    - *Jot down any questions for the midweek progress check in class.* (Be sure students know, though, that they are not limited to that time to ask you for clarification or answers to questions.)

3. Touch base to provide clarification and address questions. (Wednesday)

Touch base midweek with students to make sure they are on track while working independently. You may choose to administer a midweek minute-quiz to give students a concrete reason not to postpone completing the reading until the last minute. Ask questions such as these, and have students jot answers on a half sheet of paper:

Suggested prompts	Sample student responses
What are some design solutions used to reduce injuries to car passengers or bike riders during collisions?	*crumple zones, airbags, seat belts, and helmets*
When two objects collide, how do you know which one was responsible?	*If only one of the objects is moving, that one is responsible. If both objects are moving, it is harder to tell—they may both be responsible.*
What can a simple diagram of a collision show?	*It has symbols for the objects in motion, their masses, and the direction in which and the speed at which they are moving.*
Where in nature do collisions happen that do not involve humans?	*when hail hits Earth's surface* *when ocean waves hit a rocky coast* *when male bighorn sheep fight* *when a long tom fish strikes another fish*
What is kinetic energy, and how is it part of collisions?	*Kinetic energy is energy that objects have because they are in motion. It may transform into other forms of energy upon a collision.*

Ask a few brief discussion questions related to the reading that will help students tie the text content to students' classroom investigations.

Suggested prompts	**Sample student responses**
What kinds of damage were discussed in the first reading? How does that contrast with the kinds of damage we discussed in class?	*In the reading, the damage was to cars as they crumpled and injuries to the people inside them.* *In class, we mostly talked about damage to objects such as a dropped phone.*
How does the information about frames of reference (point of view) from the reading relate to discussions we had in Lesson 1?	*In class, we decided that the type of collision does not change just because you change your point of view.* *The reading pointed out that all objects are always moving and that sometimes we can tell which objects caused a collision, depending on the frame of reference.*
How do the diagrams of collisions we made in Lesson 1 compare with those shown in the third selection?	*We used square shapes to show the objects that collided, and the reading uses round shapes.* *We drew a few short lines to show motion, and the reading uses green arrows.* *We identified the objects that collided but did not show their masses, while the reading showed masses but did not identify the objects.*

- Refer students to Exercise Page 1. Provide more specific guidance about expectations for students' deliverables due at the end of the week.
    - *The writing expectation for this assignment is to draw a concept map summarizing big ideas and details from the four readings in this collection.*
    - *You might want to list and refine your big ideas and details first and later draw a map to display them.*
    - *The topic "Collisions" is the title of your map, so try writing it in large bold lettering.*
    - *When you are trying to summarize the big idea of a reading, look at the titles and headings for inspiration.*
    - *Choose supporting details that you found most interesting.*
    - *The important criteria for your work are that your concept map summarizes the science and details accurately and that it is easy to interpret.*
- Answer any questions students may have relative to the reading content or the exercise expectations.

Exercise Page

EP 1

4. Facilitate discussion.

(Friday)

Facilitate class discussion about the reading collection and writing exercise. The four readings in Collection 1 explore engineering designs to prevent injuries in collisions, how to describe collisions using frames of reference and models, and examples of collisions involving the natural world.

Pages 4–13 **Suggested prompts**	**Sample student responses**
What is the general purpose of the first selection, "Designing for Collisions"?	*It explains how several designs to reduce injuries to passengers in car collisions work.*
What is the meaning of design *in the context of this reading about collisions?*	*Design is how something is built to solve a problem, such as preventing injuries to car passengers in collisions.*
How have automotive engineers combined solutions to solve one problem?	*They designed crumple zones, airbags, and seat belts to reduce injuries in a car collision.*
What related questions about keeping people in moving cars safe could we investigate?	*What kinds of materials make the best crumple zones in cars?* *How much do airbags reduce head injuries?* *How well do crumple zones, airbags, or seat belts work when the car rolls over in a crash?* *Do some designs of bike helmets work better than others?*
What is the general purpose of the second selection, "Describing Collisions"?	*It explains that understanding which object struck another object in a collision depends in the frame of reference—or point of view.*
What can you infer the writer meant by momentum *in the section about the head-on collision in which the rear end of one car moved up in the air?*	*It meant the back of the car didn't stop, even when the front stopped by crashing.* *It meant that objects in motion tend to stay in motion.*
From where could you observe that a building on Earth is moving?	*from a position out in space looking at Earth spinning on its axis and revolving around the sun*
Why can someone's directions to turn left or turn right be confusing?	*because you don't know if they mean from their point of view or from your point of view*
What is the general purpose of the third article, "Modeling Collision Systems"?	*It explains how it is useful to use models to visualize and predict what will happen during collisions.*

Student Reader

Collection 1

SUPPORT—If you are using the recommended word envelope convention, check the envelope to see if it contains any words, phrases, or sentences that students need help understanding. Read key sentences aloud, and provide concise explanation.

Online Resources

SUPPORT—Remind students that a force is a push or pull. Then explain that a contact force is a push or pull in which the object exerts force by touching the object that it moves. Contrast this with noncontact forces, such as the gravitational pull of Earth on a person jumping off a diving platform.

Pages 4–13 **Suggested prompts**	**Sample student responses**
In the drawn models, what does the point on the green arrow show? What might the different lengths of the green arrows mean?	*The arrow points in the direction of motion.* *The length of the arrow might mean how fast each object is moving.* *It might mean that the object with the smaller mass has a greater speed (longer arrow) than the object with a larger mass (shorter arrow).*
Look at the photo of the drone and airliner. Would a model drawn like those above it accurately predict a collision or near miss?	*no, because those diagrams do not show altitude* *From the point of view of someone on the ground, you cannot easily tell how high off the ground each object is and whether they might collide.*
What do you know about this scene that might suggest that a collision will NOT take place?	*I know that drones are usually very small and airliners like the one shown are huge. So, if they look the same size to me on the ground, the airliner must be very far above the ground.* *I know that drones may only be flown close to the ground and airliners are usually very high off the ground, except when they are landing or taking off.*
What is the general purpose of the fourth article, "Beyond Cars and Crashes"?	*It explains and gives examples of collisions in nature.*
How can you use what you learned in the second selection about points of view (frames of reference) to interpret these photos?	*The first pair of photos shows a point of view looking downward on the hood of the car and at hailstones on a hand. Since the collisions are in the past, nothing appears to be moving (even though Earth is spinning).* *In the next photo, the photographer is probably standing on a hill on the coastline. From that point of view, the ocean water is moving, and the rocky coast is not moving.* *In the third photo, the ground and the one sheep on the far right are not moving, but the two rams butting heads are colliding.* *In the photo of the fish, we don't see a collision, but the fish are probably moving in the direction they are pointing.*

SUPPORT—Explain to students that when a moving object has a lot of inertia, it is hard to stop. This is one reason that when a driver applies the brakes, a car takes some time to actually come to a stop. Discuss what students may intuitively know about mass and momentum—that a big, heavy truck has more momentum than a small, lighter car.

CHALLENGE—Students are likely aware that concussions are brain injuries, often caused by collisions, that can have long-term health effects. Have interested students list questions they have about concussions and do online research to get answers. Before they begin independent research, discuss how to recognize reputable science websites.

EXTEND—Have students use online word cloud generators to visualize the words that are most often used in the collection. Display some of the word clouds in your classroom and have students use the images to summarize the content of the collection.

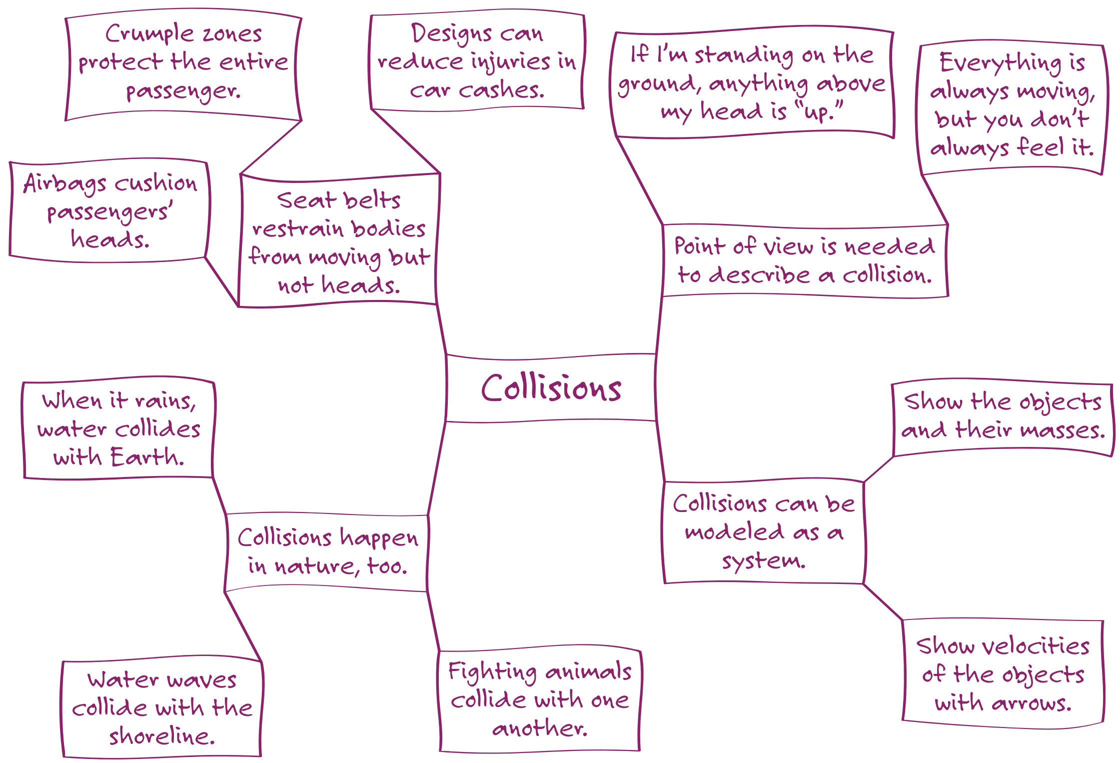
Pages 4–13 **Suggested prompt**	**Sample student responses**
	In the photo of the moose, the sign and moose appear to be stationary, even though they are all spinning with Earth. *In the photo of the right whale, the point of view is likely from a small boat looking at the side of the whale. So, the whale probably seems to be moving toward the left. The ocean water may also be moving up and down and side to side with the little waves but not actually getting anywhere.*
How is the photo of the fighting rams similar to a photo in the second selection?	*It is similar to the photo of the two cars crashing head-on in the second selection. In other examples, there is a collision of two objects of about the same mass on the same place (the ground).*

5. Check for understanding.

Evaluate and Provide Feedback

For Exercise 1, students should draw a concept map showing big ideas and details related to collisions.

- A sample map is shown at right, but students may choose other big ideas and details that they deem interesting to highlight.
- A well-drawn concept map should be easy to read, with connections between the ideas clear. The arrangement on the page, colors, and shapes that contain text may vary from the sample.
- Look for evidence that students followed the directions to show ideas from all four selections in this collection.



LESSON 3

Do all objects change shape or bend when they are pushed in a collision?

Previous Lesson

We explored colliding objects and recorded observations about changes in their motion and shape. We analyzed slow-motion videos of some of these collisions. We developed a model to represent what we know about energy transfer and forces occurring in collisions when we see changes in motion of objects, shape of objects, or damage to objects.

This Lesson

Investigation

1 DAY

We make a claim about whether all solid objects bend or not when pushed during a collision. We analyze slow-motion videos, carry out an investigation with a laser and a mirror, and analyze a concrete joint load testing video. We use these sources of data to argue for whether our original claims are supported or refuted by the evidence.

Next Lesson

We will plan and carry out an investigation into the relationship of contact force applied and the amount of deformation that occurs in different materials. We will graph our data and compare our graphs to those from other materials tests. We will develop a model to explain and represent the elastic and nonelastic behavior of all solid objects in response to varying amounts of force applied to them.

Building Toward NGSS

MS-PS2-1, MS-PS2-2, MS-PS3-1, MS-ETS1-2, MS-ETS1-3, MS-LS1-8

What Students Will Do

3.A Construct and revise a written argument using evidence from various sources of data (slow-motion videos, photos, and firsthand investigations) to support or refute the claim that all objects do bend or change shape when pushed in a collision.

What Students Will Figure Out

- All solid objects bend or change shape when pushed on in a collision and when other contact forces are applied to them.

Lesson 3 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	6 min	**NAVIGATION** Recall from the previous lesson examples of objects that changed shape or bent during (or from) a collision and make predictions about whether all objects bend or change shape in collisions. Establish an initial claim about whether this happens to all objects when they are pushed in a collision.	A-B	*Claim and Observations Organizer*
2	5 min	**ANALYZE VIDEO CASES** Analyze slow-motion videos for evidence of objects bending in a collision. Record observations and determine if observations support or refute the claims made.	C-H	*Claim and Observations Organizer*, computer, projector, videos A, B, and C (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**)
3	5 min	**DISCUSS FINDINGS AND INTRODUCE CONTACT FORCE** Discuss observations from the videos and introduce the term *contact force*. Add *contact force* to the Word Wall.	I-J	
4	12 min	**PREDICTING AND TESTING OUR PREDICTIONS FOR APPLYING CONTACT FORCES TO A PIECE OF GLASS** Collect data on how laser light reflected off a surface (glass) is affected when an object is dropped onto the glass and when a static weight is placed on the glass.	K	*Claim and Observations Organizer*, Reflected Laser Investigation
5	4 min	**MAKE PREDICTIONS AND ANALYZE CONCRETE LOAD TESTING PHOTOS** Poll the class on their initial predictions and show a timelapse video from load testing a concrete joint. Have students make observations to determine if this case supports or refutes their claim.	L-M	
6	5 min	**EVALUATE AND REVISE INITIAL CLAIMS** Evaluate and revise the claim made about objects changing shape and use this claim to make an argument about whether objects change shape when a force is applied.	N	*Claim and Observations Organizer*
7	8 min	**NAVIGATION** Reflect on concrete double tee bridge joint findings and determine how we can test the amount of force needed to bend any object.	O-Q	
				End of day 1

Lesson 3 • Materials List

	per student	per group	per class
Reflected Laser Investigation materials			• 1 rolling cart • 1 ring stand • 1 test tube clamp • 1 laser pointer • 1 clothespin • optional: 1 box to raise the height of the ring stand • 1 classroom lab table • 1 sponge • 3 2″x4″ pieces of flexible stick-on mirror material • 2 bricks • 1 rectangular piece of glass (15″ long x 8″ wide) • tape to secure glass to bricks • 1 cup half-filled with rocks • 1 golf ball • chart paper • tape • 1 pencil or marker
Lesson materials **Student Procedure Guide** **Student Work Pages**	• *Claim and Observations Organizer* • science notebook		• computer • projector • videos A, B, and C (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**)

Materials preparation (15 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Test these videos ahead of time:

- videos A, B, and C (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**)

Online Resources

- Concrete joint (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

Reflected Laser Investigation

- **Group size:** whole class
- **Setup:** One setup is needed for the whole class and is reused for all classes. Set up a laser on a ring stand on a rolling cart and the materials you are going to shine the laser on as shown in the setup video (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**). Watch this video to also see the anticipated results that testing the piece of glass and the classroom tabletop should yield when you do this investigation live with the class. There are three locations to set up for this investigation: (1) the ring stand-mounted laser on a cart, (2) the materials you are testing for deformation, and (3) the spot on the wall or whiteboard the reflected laser beam shines on.
    - (1) materials needed for the ring stand-mounted laser on a cart
        - 1 rolling cart
        - 1 ring stand
        - 1 test tube clamp
        - 1 laser pointer
        - 1 clothespin
        - optional: 1 box to raise the height of the bottom of the ring stand
    - (2) materials you are testing for deformation
        - 1 classroom lab table
        - 1 sponge
        - 3 2″ x 4″ rectangles of flexible, stick-on mirror material
        - 2 bricks
        - 1 rectangular piece of glass (15″ long x 8″ wide)
            - add one piece of flexible, stick-on mirror material from above to the center of the glass
        - tape to secure glass to bricks
        - 1 cup half-filled with rocks, sand, or washers
        - 1 golf ball
        - 1 hardbound book to drop on table
    - (3) the spot on the wall or whiteboard the reflected laser beam shines on
        - chart paper
        - tape
        - 1 pencil or marker

- **Safety:**
  - Wear safety goggles or glasses during the setup, hands-on, and take-down segments of the activity.
  - One should exercise the same safety precautions around lasers as with any other power tool or electrical device, paying special attention to eye safety. **Never** point a laser in someone's eyes—even low-power, handheld units can cause eye damage due to the focusing effect of the lens in the eye. Have students stand out of the path of the laser.
  - Glass can shatter easily if too much force is applied to it and it is bent too far. Do not drop the golf ball onto the glass from more than a height of 2 inches. Do not place more than half a cup of sand, rocks, or washers in the middle of the glass.
  - Wear cut-resistant gloves when handling glass.
  - Never eat any food items used in a lab activity.
  - Make sure all other fragile items are removed from the test area.
  - Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
- **Disposal**: If glass breaks, do not handle with bare hands. The broken pieces will be very sharp and should be swept up with a broom and dustpan. Make sure to follow guidelines set forth by the school or district for disposal.
- **Storage:** Make sure to unclip the laser and turn it off between each class to avoid draining its battery.

Lesson 3 • Where We Are Going and NOT Going

Where We Are Going

Prior to the middle school grade band, students often encounter the idea that solids are defined as matter that holds its shape, as opposed to liquids, which take the shape of their container, or gases, which fill the volume of the container they are in. This may lead them to group solids into two categories: stiff objects that aren't elastic and objects that are visibly elastic like rubber bands or springs.

Many solid objects are so rigid they don't appear to be elastic when small forces are applied to them. However, all solid objects are elastic up to a certain amount of force applied to them. In many cases, the amount of deformation is so small when small amounts of force are applied to a solid object that it can only be detected with special measurement devices.

The idea that all objects are elastic (or springy) up to a point (the elastic limit) and return to their original shape when the forces are removed is one that students will start to develop across this lesson and the next. This idea will help provide students a mechanism to explain why inanimate objects push back (or pull back) on anything that pushes on them (or pulls on them) within a certain range of forces. This will be used to help students explain what causes Newton's third law between two objects in contact with each other. This connection is something they will uncover in Lesson 5.

Where We Are NOT Going

We are not trying to distinguish between elastic and inelastic collisions in this unit. In the next lesson, we will introduce the word *deformation* to describe the different types of shape changes an object can undergo (temporary vs. permanent deformation). When a material encounters an external force, it experiences internal resistance to the deformation and restores itself to its original state if the external force is removed.

1. Navigation

6 MIN

Materials: *Claim and Observations Organizer*, science notebook

Recall the question we decided we needed to investigate last time. Say, *Last time, we were looking at slow-motion video and noticed some surprising shape changes happening in some objects during a collision. That led us to realize we had a new question to investigate further which we took a poll on and brainstormed some ways to investigate it.*

Project **slide A**. Give students a couple of minutes to discuss the questions on a slide with a partner and then discuss the questions as a whole class.

Suggested prompts	Sample student responses
What was the question about shape changes in collisions we took a poll on at the end of our last class that we decided we needed to investigate further?	*Do all objects bend or change shape in a collision?* *Does the force from a collision always cause shape changes in the objects that collide, but sometimes we just can't see or detect it?*
What were some types of objects or materials you brainstormed in your notebook that are very rigid and that could be useful to test in order to investigate this question?	*Accept all answers. Get at least 10 different possible answers.*
What about things like the glass marble or the golf ball from the previous lab? Do you think those materials we didn't see bend with our own eyes are actually bending, but it's just really hard to see?	*Accept all answers.*

Say, *This sounds like a lot of objects to test. And though we know we can't test all objects in existence to answer our question, we would need to test at least some of these in order to have sufficient evidence to answer our question. Let's get ready to do that.*

Introduce the organizer and make a claim. Project **slide B**. Distribute *Claim and Observations Organizer* to students and have them add it to their notebooks. Explain that students will use *Claim and Observations Organizer* to record their claim as well as the data they collect from a variety of sources to help them keep track of whether their claim is supported or refuted by the evidence.

Say, *We have two competing claims in our classroom. Some of us think that all solid objects bend or change shape in a collision, while others of us think that not all solid objects bend or change shape in a collision. In a moment we'll start collecting data to serve as evidence to support or refute these two different claims. Our first source of evidence will be from three slow-motion videos of different objects colliding. As scientists, we always want to record our thinking to help us compare our findings. So let's start recording this by filling in the blank in this initial claim section on your handout.*

*** Supporting Students in Engaging in Argument from Evidence**

Claim and Observations Organizer supports students in engaging in argument from evidence by providing a structured way to record evidence from our investigations. Students will use the evidence collected on the handout to support or refute their original claim, All solid objects [do/do not] bend or change shape when pushed in a collision. This process of making a predictive claim and then collecting data to support or refute it was introduced in the second lesson of the first unit in the 7th grade scope and sequence. The alternate arguments that students had established were around whether the gas produced when a bath bomb was added to water was part of the bath bomb to start with (trapped in it) *or* made from the matter that was in the bath bomb.

*** Attending to Equity**

Universal Design for Learning: Use classroom norms to support *engagement* by creating a space where students are not worried about being right or wrong. Referencing this norm brings back the idea that scientists change their

Guide students in completing the claim by filling in the blank with one of the following claims that they initially agree with:

- All solid objects *do* bend or change shape when pushed in a collision
- All solid objects *do not* bend or change shape when pushed in a collision

Say, *Remember, one of our norms is that we work together to figure things out, and it is OK if we are unsure at this point. It doesn't matter if our original claim is right or wrong; right now it is important for us to determine what evidence we need to collect in order to support or refute our claims. We can always change our claims if we need to as we gather more evidence. That's what scientists do!*

thinking in light of new evidence, and uncertainty is part of science. The classroom norms support uncertainty and remind students that through our diverse thinking, the class will collectively grow in our pursuit to understand the science ideas and make a final claim.

2. Analyze video cases. 5 MIN

Materials: science notebook, *Claim and Observations Organizer*, computer, projector, videos A, B, and C (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**)

Project **slide C**. Have students look at the "Data source" column of *Claim and Observations Organizer*. Explain that this column has the three videos we will watch listed for them as well as additional blank rows for some other investigations we will do together. The second column is for recording observations, and the third column is for students to record if the observations they make support or refute their initial claim.

Project **slide D**. Point out the three different collision video descriptions to students. Explain that each video will be played twice. The first time it is played, they should pay attention to what is occuring, but not record anything yet. During the second viewing they should record their observations. After viewing all the videos students will have time to decide if their observations support or refute their initial claim.

Play videos and record observations. Project **slide E**. Check that the computer sound is turned off during the playing of the videos. Play video A (see the **Online Resources Guide** for a link to this item), which will be shown in its entirety twice. Instruct students to watch the video the first time and to record observations during the second viewing. Continue this process with **slides F** and **G**.

Show video clips A, B, and C to students.

Project **slide H**. After showing the 3 videos, give students time to review their observations. Have them decide if their observations support or refute their original claim.

*** Attending to Equity**

Supporting Empathy and Emotions: The first video in this sequence is of a slow-moving car hitting the bumper of another car. The car is moving at a very low rate of speed, and minimal impact is given to the car in front of it. The video was included in this sequence because it shows a type of interaction that was previously classified and does an excellent job of showing an object bending and changing shape. Even though the collision is happening slowly and at a slow rate of speed, this may bring up adverse experiences for some students. If students choose not to watch this video, it will not take away from the overall learning experience. Use your discretion showing video A.

3. Discuss findings and introduce contact force. 5 MIN

Materials: None

Take a poll. Display **slide I**. Read the poll to students, *Do really solid objects bend or change shape when pushed during a collision?*

Ask students to give a thumbs up for yes or a thumbs down for no. Ask a few students to explain their reasoning, both from students who voted yes and from students who voted no.

Suggested prompts	Sample student responses
It seems like we have two different ideas here. Would someone who gave a thumbs up explain their reasoning?	*The golf ball was pretty hard and it bent, so maybe other things do too.* *A baseball bat doesn't look like it bends, but it does. Maybe other things bend and I just don't see them.*
Would someone who gave a thumbs down explain their reasoning?	*I saw a lot of things bend, but I didn't see the golf club bend when it hit the golf ball. I don't think all things bend, just certain things.*
Is it possible that when an object pushes on another in a collision, it may not appear to change shape when it is actually doing so, but just at a scale that is too hard for us to see?	*Accept all responses.*

Say, *We need to resolve this question about whether all objects bend or not in a collision so that we know how this idea applies to the sort of materials like those in a collision between a glass phone screen and a concrete floor. Let's collect some additional observations to see if we can get evidence for whether those objects bend when they get pushed on too.*

Introduce the term *contact force*. Say, *Before we move on to do that, we have been talking a lot about pushes that happen in a collision. We know from elementary school that a force is a push or a pull, and scientists have a name for the force that an object experiences due to contact with another object. It's called a* contact force. Add *contact force* to the Word Wall.

Discuss class findings. Show **slide J** and read the first sentence to students. Give students a couple of minutes to read and answer the questions on the slide with a partner before eliciting responses from the class.

Suggested prompts	Sample student responses
If we applied a contact force to something like a piece of glass on our phone screen by pushing on it with another object, do you think you would see it bend or change shape before it broke?	*I know sometimes I can press really hard on my screen and it changes colors. I think some glass can, but not all glass.*
If we applied a contact force to a thick piece of concrete by pushing on it with another object, would you expect to see a change in shape before it breaks?	*I don't think it can. I can't press on glass without it breaking. It's pretty breakable. But maybe it just bends so little that I can't see it.* *I've been in a parking garage, and it seems like the concrete ground moves when cars drive over it. I think it can, but maybe we just can't see it.*

Suggested prompts	Sample student responses
	I don't think you would see a shape change before it breaks. Cars drive on roads made of concrete, and I haven't seen it bend. The concrete is not going to bend for every car that goes across it.

4. Predicting and Testing Our Predictions for Applying Contact Forces to a Piece of Glass

12 MIN

Materials: Reflected Laser Investigation, science notebook, *Claim and Observations Organizer*

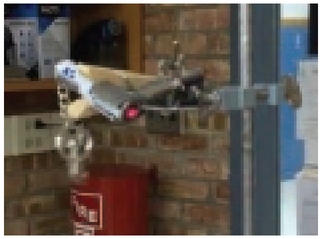
Introduce how the laser and mirror can detect shape changes in an object. Hold up a sponge with a piece of flexible stick-on mirror material attached and then point to the top of the table at the front of the room as you say, *I have a sponge. This sponge visibly bends and deforms easily when we apply a contact force. I also have a piece of glass at the front of the room. We have been wondering if our phone glass changes shape or bends in a collision, so let's use this piece of glass to test this! It's really hard to view this in slow motion, so I have another tool we can use to detect really small changes in the shape of an object. We are going to use a mirror and laser to magnify any time the surface of an object bends or changes shape.* Let's try it on the sponge first so we can see how it works, and then we can see if it does something similar or different with this piece of glass.*

Show **slide K**. Have students bring their science notebooks opened to their handouts and a writing tool and gather on either side of the table at the front of the room.

The steps outlined below are demonstrated in video for your reference. (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**) Watch this video beforehand to see examples of all the surfaces being demonstrated. Follow similar steps when you demonstrate this equipment with students.

Place the stick-on mirror material, bricks, sponge, and piece of glass near the center of the table.

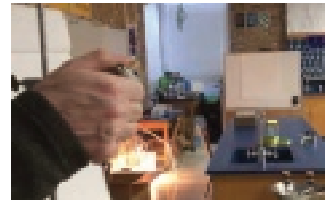
Go over to the laser cart and turn on the laser by clamping the clothespin down over the "on" button.



*** Supporting Students in Developing and Using Scale, Proportion, and Quantity**

This emphasis on needing to use a specialized instrument to detect changes happening at a scale we can't see directly with our eyes will again help emphasize the crosscutting concept of scale. It will also help students recognize that phenomena observed at one scale may not be observable at another scale, and the function of natural and designed systems may change with scale.

Move the cart and position the laser so that the laser dot is hitting the top of the sponge on the table.



Put a piece of the stick-on mirror material on the center of the sponge. Show that when you push on the sponge, the stick-on mirror material remains stuck to the surface and moves as the sponge moves, tilting a different way depending on how the shape of the sponge surface changes. Move the sponge as needed so that the laser is shining on the stick-on mirror material.

The reflected laser dot should bounce off the stick-on mirror material and appear on the opposite wall or a whiteboard on or near the chart paper you put up ahead of time. Move the chart paper if needed so the reflected laser dot shows up on it.

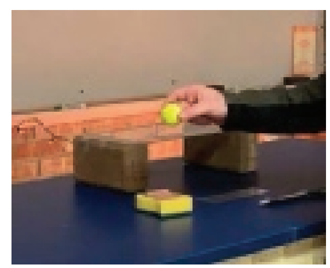
Encourage students to line up along the path of the reflected laser light so everyone can see the dot on the chart paper. Tell them to be careful not to block the laser light for the next tests. Explain that you are going to push on the sponge to make its surface bend and change shape, and you want them to watch what happens to the dot on the chart paper. Push down on the sponge with your hand.

Ask students to describe what happens to the reflected laser dot when you apply a force to the sponge and why. Students should say they see it move and that this is because the position or orientation of the surface of the sponge changes when the shape of the sponge changes.

Ask students whether the laser would move if you dropped something on the sponge and why. Also ask if they expect it to move if you put a weight on top of the sponge. Students will predict “yes” in both cases because both cases should cause the shape of the sponge to change.

Demonstrate how the sponge and reflected laser dot respond to these other contact forces. Direct students to write “sponge and laser” as a new data source on their handouts, directly under “moving baseball colliding with a motionless bat.”

Demonstrate both cases, first by dropping a golf ball on top of the sponge. Make sure you drop it to the side of where the laser beam is shining so as not to have it fall or bounce up through its path. Have students describe what happened to the laser dot on the chart paper when you did this. They should say it moved.



Next, put a weighted cup on the sponge, again, out of the path of the laser. Ask students what it did to the laser dot. Students should say it made the dot move. Ask them what the downward push from the weight of the cup did to the shape of the sponge. Students should say it bent or compressed it.

Allow students to record observations on their handout next to the "sponge and laser" data source. Tell them not to worry about the "support or refute" column just yet—our focus at the moment is making observations.

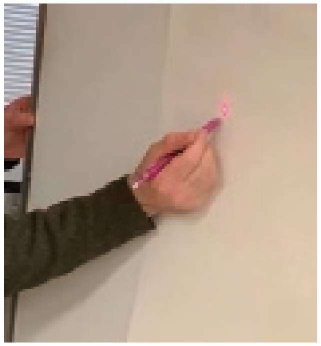
Use the equipment to test a new system (the piece of glass). Ask students to extend what they saw to explain how this method can be used to see if glass bends or changes shape. Direct students to write in a new data source, "mirror and laser", directly under the "sponge and laser" row.

Suggested prompts	Sample student responses
So what does the laser dot do when the mirror moves or tilts due to shape change in the object it is stuck to?	*It shifts position.*
Let's get ready to stick the mirror material to a piece of glass. If we then push on the piece of glass or the table by dropping something on either or resting a weight on either, what would we see happen to the laser dot if the object underneath the mirror bends or changes shape?	*The laser dot will shift position.*
What if those objects don't bend or change shape?	*The dot won't move.*

Shift the laser or the bricks and glass so the dot is now hitting the stick-on mirror material on the glass lying across the two bricks. Optionally, tape the glass to one or both bricks for more stability. The laser dot should bounce off the mirror material and show up on the chart paper. Smooth out the mirror material if the dot isn't concentrated in one spot on the paper.

From 1-2 inches above the glass, drop a golf ball on the side of the glass that is out of the way of the beam of the laser dot. Make sure not to drop it from a height greater than 1-2 inches to avoid shattering the glass. Have students describe what happened to the dot.

Emphasize that this might be evidence of the glass bending or it just might be evidence of the mirror and glass bouncing a bit. Say that keeping the mirror and glass from bouncing might help us better determine if the glass is actually deforming. Have a student mark the bottom edge of the laser dot on the chart paper. Explain that this is so we can see if it moves from that position after we put something on top of the glass.



Place a cup half-filled with rocks in the middle of the glass but out of the way of the laser beam. Explain that the weight of the rocks resting on the glass will apply a force to the glass. Have a student mark the bottom edge of the laser dot and report if it moved from the previous position. They should say yes.

Ask students to add a record of this set of observations on their handout.

5. Make predictions and analyze concrete load testing photos. 4 MIN

Materials: science notebook

Organize students in a semicircle around the projected slides. Project **slide L**. Say, *We have figured out something about how glass behaves when a force is applied to it from something else making contact with it, but what about something like the floor that is made from a material like concrete*?

Make predictions. Ask students the question on the slide and take a poll. Use a quick count of thumbs up and thumbs down to check student predictions. Direct students to write "concrete joint timelapse video" as our last data source on the last empty blank in the "Data source" column of their handouts.

*** Supporting Students in Developing and Using Stability and Change**

Previous to this activity, students have looked at collisions by slowing down the interactions. So far collisions have occurred too

Analyze the results from the concrete testing. Display **slide M**. Tell students that the images they will be analyzing were from a video of engineers testing how a concrete joint responds to different amounts of contact force applied to it. Explain that they are going to see timelapse of a video from such a test where engineers slowly increase the amount of downward force applied to the concrete joint and then observe how the joint responds. The timelapse was sped up 64x from the original speed so we can see if any changes occurred in a shorter period of observation time rather than watching the entire test in real time.

Have students look for changes in the videos. Before pressing play say, *As the video plays, the engineers are applying a greater amount of downward force. Watch closely so we can see if there is any change in shape associated with the force they are applying to the joint.* Start the videos A, B, and C (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**) and allow the videos to play once in entirety. Ask students if they want to see any of the videos again, and replay if students wish to see it a second time. Give students a chance to record their observations on their handouts.

Say, *OK, we've seen the results from applying more and more contact force to a concrete joint. Go back now and evaluate all the data we've collected on the handout to determine if any of it supports or refutes your initial claim. Even if we were in disagreement at the start of the period, all the different data we analyzed should provide us adequate evidence to evaluate those initial claims and, if needed, revise them so we are all in consensus on what common claim we can now all make about our original question.*

quickly to see without slowing them down. Now, students are looking at changes over time that are happening very slowly, and some of these changes could not be perceived without speeding up the process.

Students have had experiences with slow change over time before, such as the rate of plate movement in *Unit 6.4: How and why does Earth's surface change? (Everest Unit)*. They also determine that large sections of rock (in plates) can bend when large forces are applied to them. If students raise this idea, emphasize this connection to the entire class.

6. Evaluate and revise initial claims.

5 MIN

Materials: science notebook, *Claim and Observations Organizer*

Display **slide N**. Have students open their notebooks to a clean page and write their initial claim. Give students time to answer the questions on slide N in their notebooks. Refer students back to their observations organizer on the handout to help them determine if the data support or refute their original claim and summarize how the evidence from our investigations helps support or refute their initial claim.*

Assessment Opportunity

Building towards: 3.A Construct and revise a written argument using evidence from various sources of data (slow-motion videos, photos, and firsthand investigations) to support or refute the claim that all objects do bend or change shape when pushed in a collision.

What to look/listen for: By this point in the lesson, students should provide evidence and support or refute their original claim to reflect that all objects *do* bend or change shape when pushed in a collision.

What to do: If students are not in agreement that all objects bend or change shape in a collision, observe what evidence the students have collected in their organizers to verify that the evidence was recorded correctly. If any evidence was not recorded accurately, have students review that part of the investigations and compare this with their evidence on their handouts. Ask students to refer to the evidence collected from the laser investigations and the concrete joint video to support or refute their original claim. All the observations made by students should provide evidence that the objects are changing shape or bending as a force is applied. The one exception would be the head

*** Supporting Students in Engaging in Argument from Evidence**

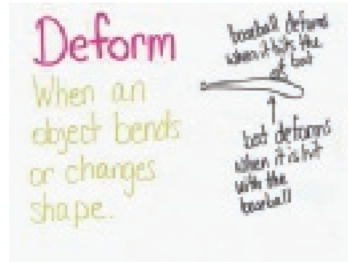
During the course of the lesson, students have engaged in investigations to determine if all objects bend or change shape in a collision. Students are now given the chance to go back and revise their thinking around their initial claim. By using evidence from the investigations, students reason why they support or refute their original claim.

*** Attending to Equity**

Emerging Multilingual Learners: A Word Wall will become a useful space for recording a shared meaning of new words as students of the golf club when it strikes the golf ball. But by the end of the lesson, students should be able to argue that it too may actually bend or change shape, but this may be occuring at too small of a scale for us to see in the video. If students are still struggling with this concept, pull up each video again at the start of the next lesson and/or go over the glass demonstration individually with students, making sure that they are observing that the objects are indeed changing shape when a force is applied. Pointing out the observations and helping students connect the observations to their claim will help students understand the key idea.

Introduce a new word. Say, *We have been talking a lot about objects bending or changing shape. Scientists call this* deformation. *When an object bends or changes shape, it deforms.*

Add *deform* to the Word Wall.*



develop a deeper meaning for them. When developing new vocabulary, some strategies that may benefit emerging multilingual learners are to use student-friendly definitions, make connections to cognate words when possible, and include a visual representation of the word. Students may find it helpful to have you add additional images of objects deforming, both permanently and temporarily, next to the word *deform* on the Word Wall in the next lesson as well.

7. Navigation

8 MIN

Materials: science notebook

Poll students over concrete joint findings. Remind students of the images of the concrete joint that they have previously viewed. Point out that the object was seemingly very strong and rigid before the test, but it ended up deforming quite a bit before breaking. It deformed even though it appeared very solid and rigid at the start.

Display **slide O** to gather results on the poll for this question:

- How many of you were surprised by the results of the concrete joint test?

Have students give a thumbs up if they were surprised and a thumbs down if they were not surprised.

Say, *The engineers applied more and more force to the joint, and it made it deform before it broke.*

Display **slide P** to gather results on the poll for this question:

- Do you think that the concrete joint began to deform with a small amount of contact force at the start of the test or did it take a lot more force to start bending it?

Have students give a thumbs up if they think it started bending with a small amount of contact force applied to it and give a thumbs down if they think it didn't start bending with a small amount of contact force applied to it and it needed more force before it started bending.

Say, *We have seen how a sponge, a piece of glass, and a concrete joint behave when a force is applied to them. Let's consider how* ***all*** *objects respond to any amount of forces applied to them, since ultimately we want to explain what happens in all collisions that causes objects to get damaged in some cases but not others.*

Make predictions. Show **slide Q**. Have students discuss the two questions on the slide with a partner:

- Do you think applying any amount of force to any solid object would cause it to bend?
- How could we design an investigation like the engineers did with the concrete joint test to figure out if any amount of force would cause any solid object to start bending or change shape?

After discussing these questions, say, *I am interested in hearing what you all think. Let's plan to share the ideas you discussed with your partner and also make a plan to investigate your ideas further in our next class.*

LESSON 4

How much do you have to push on any object to get it to deform (temporarily vs. permanently)?

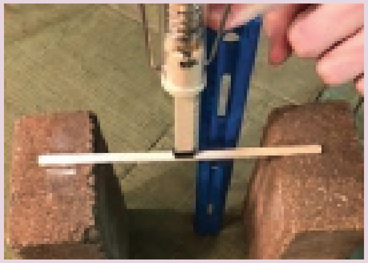
Previous Lesson

We made a claim about whether all solid objects change shape when pushed during a collision. We analyzed slow-motion videos, carried out an investigation with a laser and a mirror, and analyzed a concrete joint load testing video. We used these sources of data to argue for whether our original claims are supported or refuted by the evidence

This Lesson

Investigation

2 DAYS



We plan and carry out an investigation to look at the relationship between contact force applied and the amount of deformation that occurs in different materials. We graph our data and compare these graphs to those from other materials tests. We develop a model to represent the elastic and nonelastic behavior of all solid objects in response to varying amounts of force applied to them.

Next Lesson

We will carry out investigations to explore the strength of forces between two objects when they collide. We will plan and carry out an investigation about how different speeds and masses of objects affect the amount of peak force on each object. We will develop and use a model to represent the relationship between the energy of a moving object and the strength of the peak forces from a collision.

Building Toward NGSS

MS-PS2-1, MS-PS2-2, MS-PS3-1, MS-ETS1-2, MS-ETS1-3, MS-LS1-8

What Students Will Do

4.A Plan an investigation, identifying controls to keep constant, and carry out the investigation to produce data to serve as the basis for evidence to develop a mathematical model for the relationship (pattern) between the amount of force applied to an object and the amount it deforms.

4.B Analyze and interpret graphical data (patterns) from tests of compression force vs. amount and type of deformation (temporary vs. permanent) to provide evidence that supports an argument that all objects behave elastically up to a specific limit beyond which permanent damage occurs (stability and change).

What Students Will Figure Out

- All solid objects deform elastically when force is applied to them, up to a point.

- Different objects have different elastic limits, which is the maximum amount of deformation an object can withstand, beyond which it will deform permanently.
- Different objects have different breaking points, which is the maximum amount of deformation an object can withstand, beyond which it will crack or split apart.
- The type of material, the shape, and the thickness of an object all affect (a) how much it deforms when a force is applied to it, (b) its elastic limit, and (c) its breaking point.

Lesson 4 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	4 min	**NAVIGATION** Reflect on what we figured out in Lesson 3 and consider how to test how much force it takes to bend or change the shape of any solid object any amount (permanently or temporarily).	A	
2	7 min	**PLAN AN INVESTIGATION: MATERIAL DEFORMATION LAB** Introduce the materials we will use in the investigation and demonstrate what the push-pull spring scale measures.		Material Deformation Equipment Demonstration
3	7 min	**IDENTIFY THE VARIABLES IN THE INVESTIGATION** Discuss what the independent, dependent, and controlled variables would be for this investigation.	B-C	*Independent, Dependent, and Controlled Variables*, *Deformation Results*, *Investigation Procedures*, chart paper, markers
4	12 min	**CARRY OUT THE MATERIAL DEFORMATION LAB** Collect data in the *Material Deformation Lab*.		*Independent, Dependent, and Controlled Variables*, *Deformation Results*, *Investigation Procedures*, impact goggles, Material Deformation Lab
5	10 min	**CONSTRUCT AND COMPARE GRAPHS** Graph data from the *Material Deformation Lab* and draw and compare trend lines for their data.	D-F	*Deformation Results*, ruler (or straight edge like a wood stirrer), *Example Line of Best Fit*
6	3 min	**NAVIGATION** Make predictions about trend lines for other materials tested.	G	*Deformation Results*
				End of day 1
7	5 min	**NAVIGATION** Compare lines of best fit between different materials tested in the class using a jigsaw strategy.	H	*Deformation Results*

8	12 min	**GATHER INFORMATION** Gather additional information about materials testing.	I-J	*Results from other materials tests*
9	15 min	**ADD TO OUR PROGRESS TRACKER** Discuss key ideas we figured out in a Consensus Discussion to update the class Progress Tracker.	K	
10	10 min	**ARGUING FROM EVIDENCE** Evaluate a claim using evidence.	L	
11	3 min	**NAVIGATION** Discuss ideas about collisions in which both colliding objects are moving.	M	

End of day 2

Lesson 4 • Materials List

	per student	per group	per class
Material Deformation Equipment Demonstration materials			• 2 bricks • 3 wood stirrers taped together • a piece of duct tape or cellophane tape • 1 ruler • 15 10-N push-pull spring scales • 1 digital scale
Material Deformation Lab materials		• 2 bricks • 2 or 4 wood stirrers or Styrofoam strips • 1 push-pull spring scale (10 N) • 1 metric ruler	• transparent tape • extra wood stirrers and styrofoam strips (10-15 each)

Lesson materials **Student Procedure Guide** **Student Work Pages**	• *Independent, Dependent, and Controlled Variables* • *Deformation Results* • *Investigation Procedures* • science notebook • impact goggles • ruler (or straight edge like a wood stirrer) • *Results from other materials tests*		• chart paper • markers • *Example Line of Best Fit*

Materials preparation (20 minutes)

Online Resources

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Prepare a single class set of *Investigation Procedures* to reuse across classes.

Make one double-sided copy of *Results from other materials tests* per student.

If you are using science notebooks (9.75″ × 7.5″) and you have a paper cutter, trim all handouts to fit in the notebooks.

Make one copy of *Example Line of Best Fit* to introduce as a reference to add to the Word Wall for all your classes at the end of day 1 of this lesson.

Day 1: Material Deformation Equipment Demonstration

- **Group size:** whole class
- **Setup**
  - Put two bricks on a lab table, 14 cm apart.
  - Bundle and tape 3 wood stirrers together at both ends (using transparent tape).
  - Leave a piece of duct tape out for taping one end of the stirrers down to one brick. Regular cellophane tape may work as well.
  - Collect a class set of push-pull spring scales (10 N).
  - Set out 1 digital scale and 1 ruler.
- **Storage:** All materials can be stored and reused indefinitely.

Day 1: Material Deformation Lab

- **Group size:** 3 students
- **Setup**
  - Prepare strips of ¼″-thick Styrofoam by marking lines 2 cm apart down the length of 8.5 x 11 inch long Styrofoam panels, making strips that are 11 inches long by 2 cm wide. Cut along the lines with a utility knife or box cutter, using the side of a ruler as a cutting guide.

- Place supplies in a common area for students to pick up: Styrofoam strips, wood stirrers, and transparent tape.
- Place two bricks, one ruler, and one push-pull spring scale (10 N) at each testing station.
- Note: if you run short of styrofoam strips or wood stirrers, you can use any extra rice noodles from lesson 2 as a substitute material.

- **Safety:**
  - Wear safety goggles or glasses during the setup, hands-on, and take-down segments of the activity.
  - Never eat any food items used in a lab activity.
  - Make sure all other fragile items are removed from the test area.
  - Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
  - Immediately pick up any items dropped on the floor so they do not become a slip/fall hazard.
  - Follow your teacher's instructions for disposing of waste materials. Wash your hands with soap and water immediately after completing this activity.
- **Disposal:** Used wood stirrers and Styrofoam can be thrown away in the trash.
- **Storage:** All materials can be stored and reused indefinitely.

Lesson 4 • Where We Are Going and NOT Going

Where We Are Going

Most solid objects that are made of material that is relatively stiff don't appear to exhibit elastic behavior when observed with the unaided eye. However, all solid objects are springy or elastic (up to a point), and this can be determined through measurements at a different scale. When forces are applied to objects, they will change shape and will spring back to their original shape when those forces are removed as long as those forces don't exceed an object's elastic limit.

The elastic limit of an object is dependent on its material type and thickness. Once applied forces exceed that elastic limit, permanent deformation occurs to the object. This can be thought of as a type of damage. If external forces on the object increase further, they will eventually reach the breaking point of the object (where fracturing occurs). Different materials have different elastic limits and different breaking points.

The relationship between the force applied to an object and the amount it deforms when it exhibits elastic behavior is linear for all solid objects. The slope of this relationship is different for different types of materials. For example, a 1-cubic-inch cube of rubber will deform 0.0001 inches per 1 lb. of compression force applied to it, steel will deform 0.0001 inches per 30,000 lb. of force applied to it, and diamond will deform 0.0001 inches per 1,700,000 lb. of force applied to it.

The region of elasticity of all solid objects helps explain why objects push back on things that push on them. It provides a mechanism for explaining why objects in contact exert equal and opposite forces on each other, why collisions can cause changes in motion in the objects that collide, and why objects are damaged in some cases but not damaged in others.

Working with linear and nonlinear relationships is a target of one element of the SEP for analyzing and interpreting data in the middle school grade bands. It is also a target of the CCMS in 8th grade. This lesson is the first introduction to working with linear and nonlinear relationships in graphs in the program. Students will revisit the use and development of other linear and nonlinear models for data they collect later in this unit and in subsequent 8th grade units, such as *Unit 8.2: How can a sound make something move? (Sound Unit)* and *Unit 8.3: How can a magnet move another object without touching it? (Magnets Unit)*.

This lesson leverages students' experiences with planning an investigation where they identify an independent and a dependent variable and variables to keep constant. A standard structure on the handout for planning an investigation and identifying variables in this lesson is one that students will have used in prior units. That should help make the investigation planning in this lesson a very familiar process. Even so, you will build an anchor chart as a reference for that planning process since this is the first lesson in 8th grade where students will have encountered it, and it will be useful for them to refer to in future lessons (e.g., the next lesson) and across all subsequent 8th grade units in the sequence.

Where We Are NOT Going

The linear relationship between force and deformation is not a disciplinary core idea. The spring-like behavior of solids should be considered an important concept as it is cited in the *Framework* for NGSS: "The role of forces between particles also begins to be discussed in grade 6—topics include the recognition that particles in a solid are held together by the forces of mutual attraction and repulsion (which act like springs)" (p. 237). This lesson, however, makes no attempt to address that there are forces between particles that make up solid matter.

The elastic limit of an object is not only dependent on its material type and its thickness but also on the cross-sectional area to which the compression or tension force is applied. No attempt is made to introduce this idea, which is connected to the ratio of stress to strain an object exhibits during elastic behavior (Young's modulus of elasticity). Known values of the ratio of force vs. deformation for elastic behavior of known materials based on Young's modulus of elasticity were derived for 1-cubic-inch samples in the shape of a cube for the table used in *Deformation Results*. Force vs. deformation data used in *Deformation Results* were extrapolated from machine-produced results in the graphs reported in Khlystov, N., Lizardo, D., Matsushita, K., and Jennie, Z. (2013). *Uniaxial Tension and Compression Testing of Materials 3.032 Lab Report*. (See the **Online Resources Guide** for links to this item. **www.coreknowledge.org/cksci-online-resources**)

Engineers typically graph force vs. deformation relationships using slightly different measures: stress vs. strain. Stress is the force per unit area. This is typically plotted on the *x*-axis of a graph, and the corresponding ratio of deformation to the original object's length (strain) is typically plotted on the *y*-axis. One reason for this graphing convention is that it allows easier calculation of potential energy stored in the object, which can be done by integrating the area under the curve of stress vs. strain. Such calculations, however, are not a target idea in the NGSS in this grade band nor in high school. We wanted to make teachers aware, however, of the rationale for why in this lesson we flipped the axes on which force and deformation are typically displayed. The rationale is this: in this lesson, where force is the independent variable and deformation is the dependent variable, force is plotted on the *x*-axis and deformation is plotted on the *y*-axis, as per typical conventions when developing mathematical models of quantitative relationships.

Students are introduced to qualitative fitting of a trend line to a scatter plot of data in this lesson. No attempt is made in this or other 8th grade units to introduce linear regression to find this line. This is beyond the expectations for 8th grade Common Core Standards in mathematics. No attempt is made to calculate the slope of this line, though the data in the data table on the last page of *Deformation Results* are derived from the slope of such lines.

1. Navigation

4 MIN

Materials: None

Recall what we figured out. Say, *In our last lesson, we looked at slow-motion videos of really rigid objects, used a glass and laser setup, and looked at images of engineers testing a concrete beam. We figured out that even really rigid things can bend or change shape in collisions. We had some questions at the end of Lesson 3 about how any amount of force would affect solid objects.*

Discuss ideas with a partner. Present **slide A**. Say, *What were some of your ideas for how we could figure out if any amount of force would cause any solid object to start bending or to change shape? Turn and talk with a partner about the questions on the slide.*

- What were some of your ideas for how we could investigate if any amount of force would cause any solid object to start bending or change shape?

Say, *In the concrete beam investigation, we noticed the beam bending and then cracking and then breaking into a lot of pieces. How much force do you think it takes to bend or change the shape of any solid object any amount either permanently, like when it breaks, or temporarily, like when it bends and bounces back to its original shape?*

- How much do objects deform before they break?
- How could we tell how much force it takes to deform objects, either permanently or temporarily?

Listen for ideas such as these:

- More rigid or thicker materials take more force to deform or break.
- Very small forces might not cause this object or other very rigid objects to deform or break.
- We need a way to measure the amount of force applied to an object.
- We need to test different materials using different amounts of force.

Say, *I have some materials that I brought in for us to use. Let's see how we could use them to investigate some of the things you suggested.*

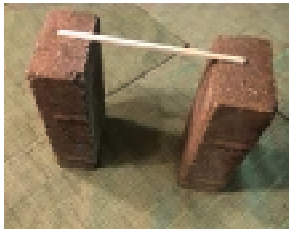
2. Plan an investigation: Material Deformation Lab.

7 MIN

Materials: Material Deformation Equipment Demonstration

Introduce the materials and how they can be used for the investigation. Go through the process below with students standing around a demonstration table.

Show the bricks and how materials can be positioned to test how much they deform in a similar way to how the engineers tested the concrete beam.



Introduce push-pull spring scales. Say, *We have a tool we can use to apply a certain amount of force to an object and measure how much force we are applying. This tool is called a push-pull spring scale. You may have seen similar scales used to weigh things like luggage, fish you catch, and produce at the market. Scientists, engineers, and others use tools like this to determine the amount of force they are applying to an object. Let's see how these work.*

Additional Guidance

Determine the mechanism for calibrating your push-pull spring scales. Before you pass these out, you may want to just double-check they all read "0" when they are held with the hook end down.

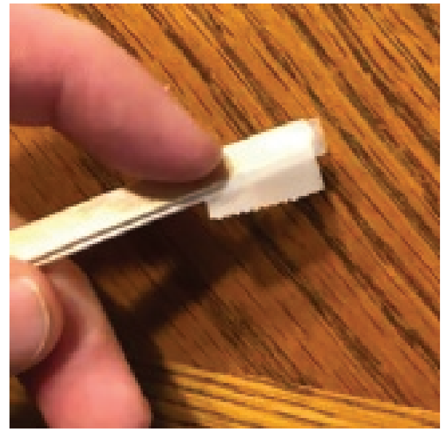
Pass around a push-pull spring scale to each group of two or three students.

Suggested prompts	Sample student responses
Take one spring scale and push on the rod. What happens to the amount of force you feel when you push on it further?	*It feels like more force back on you the further you push the spring in.*
What do you notice about the numbers on the spring scale when you push on it with more force?	*When you push it in further, you feel a bigger force and the numbers show a bigger number.*

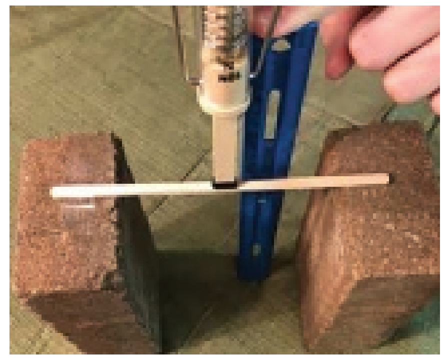
Introduce force units. Say, *In science, when we use numbers to measure something, we like to include the units that we are measuring in, like meters, feet, seconds, and hours. Sometimes engineers measure the amount of force in pounds, and sometimes they use newtons. We will use newtons. Your push-pull spring scales have markings on them that range from zero to 10 newtons, or capital N. Let's see how many pounds of force correspond to 5 newtons versus 10 newtons on the scale.*

Demonstrate how the amount of force that registers on the push-pull spring scale (in newtons) corresponds to a similar change that would be registered on a digital scale measuring the force from the weight of an object on it. Demonstrate that pushing down with 5 N force results in a measured force that is the same as a weight of just over a pound (~1.1 lb.). Push down with a 10 N force and show that the weight on the digital scale doubles to about 2.2 lb. Emphasize that both scales—the push-pull spring scale and the digital scale—are force measurement devices.

Explain that students can use this spring scale to apply more or less force to the object they are testing. Explain that you are going to demonstrate the kind of testing we could do with an example object: a 3-layer-thick beam of wood. Show the set of three wood stirrers that are taped together. Explain that different groups will be assigned different thicknesses of wood or Styrofoam strips to test in a manner similar to your demonstration.



Place the 3-layer wood beam across the gap between both bricks. Tape down one end of the material to the brick surface. Place the push-pull spring scale on the 3-layer wood beam and push down with a 2 N force. Ask students what they notice. They should say the wood deforms. Show the ruler that can be used to measure how much the beam deforms.



Say *Let's use what we've seen about this equipment so far to identify and document the variables in our experiment we want to change, measure, and control.*

3. Identify the variables in the investigation.

7 MIN

Materials: *Independent, Dependent, and Controlled Variables*, *Deformation Results*, *Investigation Procedures*, science notebook, chart paper, markers

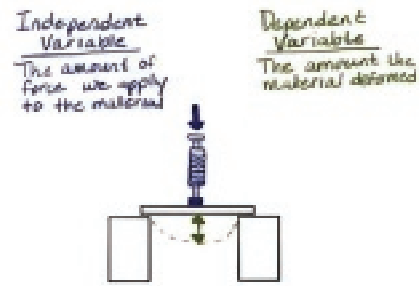
Identify the variables in the investigation. Distribute to each student a copy of *Independent, Dependent, and Controlled Variables* and *Deformation Results*. Have students take these back to their seats and tape both in their notebooks. Continue planning the rest of the investigation together as a class.

Ask students to record the investigation question, *How much do you have to push on any object to get it to deform (temporarily vs. permanently)?*, on their copy of *Independent, Dependent, and Controlled Variables*. Project **slide B**.

Draw on chart paper a sketch of the beam between two bricks they will be testing.

*** Supporting Students in Engaging in Planning and Carrying Out Investigations**
Students will be planning other investigations by identifying these variables in future lessons in this unit and in other units in this grade. Having an anchor chart and their copy of *Independent, Dependent, and Controlled Variables*

Discuss what the independent and dependent variables would be for this experiment. Review what independent and dependent variables are in general, as needed, using the text on *Independent, Dependent, and Controlled Variables*.



Add these definitions to the Word Wall:

- Independent variable—this is the variable to change each time you test.
- Dependent variable—this is the variable to observe the effects caused by a change in the independent variable.

Add this supplementary text in a different color, if needed, to further explain the variables:

- Independent variable—this is the variable to change each time you test. *This is what you are manipulating in the experiment.*
- Dependent variable—this is the variable to observe the effects caused by a change in the independent variable. *This is the results variable.*

Ask students what the independent and dependent variables are for this investigation. Students should say that the independent variable is how much we push on an object or the amount of force applied and that the dependent variable is how much it deforms. Add this to the anchor chart. Have students record these as the independent and dependent variables for their investigation.

Assessment Opportunity

Building towards: 4.A Plan an investigation, identifying controls to keep constant, and carry out the investigation to produce data to serve as the basis for evidence to develop a mathematical model for the relationship (pattern) between the amount of force applied to an object and the amount it deforms.

What to look/listen for: Look for students to do the following in the planning of the investigation:

- identify the independent variable as the amount of force applied to an object,
- identify the dependent variable as the amount of deformation in the object, and
- identify control variables, including where the force is applied and how much of the object overlaps the two supports (bricks) in each test.

What to do: If students are struggling with the ideas of variables, you may need to review some examples from previous investigations they have done in prior years. You will have multiple examples to draw from in the following units:

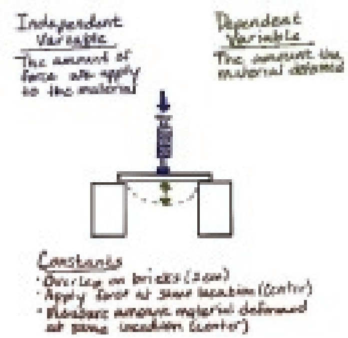
- *Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)*
- *Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit)*
- *Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)*
- *Unit 7.3: How do things inside our bodies work together to make us feel the way we do? (Inside Our Bodies Unit)*
- *Unit 7.4: Where does food come from, and where does it go next? (Maple Syrup Unit)*

will be a helpful reference to serve as an example to work from as needed, for the remainder of their investigation plans at the start of the year.

If students are struggling with the ideas of variables, you may need to review some examples from previous investigations they have done in prior years. You will have multiple examples to draw from in the following units:

- *Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)*
- *Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit)*
- *Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)*
- *Unit 7.3: How do things inside our bodies work together to make us feel the way we do? (Inside Our Bodies Unit)*
- *Unit 7.4: Where does food come from, and where does it go next? (Maple Syrup Unit)*

Remind students that we have a way to measure the amount of push by reading the amount of newtons on the push-pull spring scale. Ask for ideas about how to measure how much the object bends or deforms. Help students narrow in on the idea of recording the height of the beam before and after they push on it.



Discuss some things that would be important to keep constant in the investigation and add them to the experimental setup diagram. If students don't suggest the placement of the object and the scale as things to keep constant, ask if the location of the spring scale on the material would affect the results and if the distance between the bricks and the amount of overlap of the material on the bricks would affect the results. Suggest that all groups test their objects in the center of the beam and make sure that their beams overlap the bricks by the same amount. A 2- or 3-cm overlap is suggested. Whatever you pick as a class, write the measurement on the anchor chart. Have students record these variables to keep constant on their *Independent, Dependent, and Controlled Variables* handout.

Post and save a copy of this anchor chart for students to refer to in this unit and future units.*

Assign groups their materials to test. Have students record which material you assigned them to test above their data table on *Deformation Results*. The different options are as follows: a single wood stirrer, two wood stirrers stacked together, a single Styrofoam strip, or two Styrofoam strips stacked together. Tell groups to replace their materials with extras of these if after a test, it shows evidence of permanent deformation but has not yet cracked or broken into separate pieces.

Distribute *Investigation Procedures* to students. Project **slide C**. Tell students to use the procedure described on the *Investigation Procedures* handout to record the data from their investigation on the *Deformation Results* handout. Give students a couple of minutes to look through the procedure and then ask if there are any questions.

4. Carry out the Material Deformation Lab. 12 MIN

Materials: Material Deformation Lab, *Independent, Dependent, and Controlled Variables*, *Deformation Results*, *Investigation Procedures*, science notebook, impact goggles

Monitor lab work.** Check that groups are involving all members in the data collection. This is a lab that requires different roles in the data collection process, such as the following:

- someone to apply a given amount of force
- someone to measure amount of deformation and whether the material becomes permanently deformed or returns to its original shape after the force is removed
- someone to record these results to share with the other group members after all data are collected

Ask students to wait on graphing their data until all groups have completed collecting their data.

*** Supporting Students in Engaging in Planning and Carrying Out Investigations**
Encourage students to make careful observations and measurements in this investigation as they will be graphing their data to look for patterns that serve as evidence for cause-and-effect relationships among the amount of applied force, the type and thickness of the tested material, and the resulting permanent or temporary deformation.

*** Supporting Students in Developing and Using Stability and Change**
As students work, probe their thinking about the relationship between the type and thickness of the material tested and the amount of force needed to cause both permanent and temporary deformation. Listen for ideas about the elastic nature of different materials and how they can remain stable and return to their original shape but only to a point. Students should recognize that even small amounts of force are causing elastic deformation (stability) in these materials, and then when enough force is applied, these materials deform permanently (change).

5. Construct and compare graphs.

10 MIN

Materials: *Deformation Results*, ruler (or straight edge like a wood stirrer), science notebook, *Example Line of Best Fit*

Assign new pairs of students to work together. Pair each student so that they are working with someone with results from a different material testing group (either a different material or a different thickness of material or both).

Motivate determining common axis values. Say, *In order to compare data between you and your partner, each of you is going to have to use the same intervals on your* x-axis. *And you are going to need to use the same intervals on your* y-axis. *To determine what those should be, first look at the maximum value for each of those across both of your sets of data. Then, talk about how you can stretch out your axis to use as much of the graph paper as possible and still have room to plot the maximum* x *value and maximum* y *value. Each person only needs to plot their own data set, but both of you need to set up the same agreed-upon set of intervals for your axes before you plot your data. When you plot your data, be sure to use an open circle anywhere the beam returned to its original shape after the weight was removed, use a closed circle anywhere the beam was damaged from the weight that was added, and use an "x" at any point where your beam cracked.*

Observe *Deformation Results* for how students develop their graphs.

Assessment Opportunity

Building towards: 4.B.1 Analyze and interpret graphical data (patterns) from tests of compression force vs. amount and type of deformation (effect) to provide evidence that supports an argument that all objects behave elastically up to a specific limit beyond which permanent damage occurs.

What to look/listen for: student graphs should include the following:

- the *x*-axis labeled as the force applied to the object (in N)
- the *y*-axis labeled as the amount of deformation in the object (in cm)
- stretching out the intervals to maximize the use of the graph paper while still capturing the highest *x* value and highest *y* value
- equal intervals identified on each axis
- a straight line of best fit through the data that are represented with points drawn as open circles (anywhere the beam returned to its original shape after the weight was removed)

What to do: Since this may be the first time students have drawn a trend line in 8th grade, talk with your math teachers in 8th grade to determine when students will be encountering this idea in their math class. It is a CCMS target learning goal for 8th grade.

If students struggle with these graphing skills, coordinate with the grade-level math teacher to ask about additional contexts that students may be familiar with from math class that they can practice applying these skills to. These examples can be a useful reference for students. You may want to post these as anchor charts in your class to help students see how to transfer to their science class the ideas and skills they are developing in math.

*** Supporting Students in Engaging in Analyzing and Interpreting Data**

By 8th grade, students should be able to construct, analyze, and interpret graphed data and identify linear and nonlinear relationships. Ultimately, students should identify patterns in data to develop cause-and-effect relationships about the amount of force applied to an object and the amount of deformation that results from the applied force. Students should be able to explain the meaning of trends they notice in their data as well as what an individual data point represents.

Introduce the additional data that were collected. Say, *Next I want us to talk about how we can develop a mathematical model of the relationship you see in your data. I have a set of data for us to look at together to help us think about how to do this.*

Project **slide D**. Explain that the data on the slide were collected from three wood stirrers taped together. Emphasize that for every data point, the object returned to its original shape and position after the force was removed. Give students a minute to look at the graph and then ask them to share what patterns they notice.*

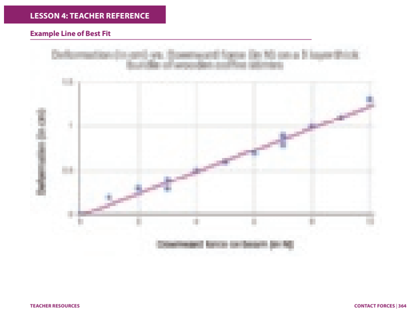
Suggested prompts	Sample student responses
What patterns do you notice in the data?	*The data look a bit scattered.*
What tends to happen to the amount of deformation as the amount of force applied to this object increases?	*It tends to increase.*
Where on the graph do we see evidence of having recorded more than one deformation measurement for a certain amount of force?	*At 3 N.*
	At 7 N.

Describe what a trend line is and how to make one. Say, *When you have multiple data points and some of them are for the same value you plotted for your independent variable, it can be helpful to plot all that data on a coordinate graph like we've done here. What we end up producing is sometimes called a scatter plot. Because we haven't averaged any of our results yet, it can be useful to think about what the average trend in all of the data is. One way to do this is to create a trend line to show how close the data are to a linear relationship. Constructing a trend line can be done by holding up a ruler or straight edge over the graph and shifting its angle and position so that the slope and y-intercept of the line it would make is as close as possible to all the data points on the graph. This line may pass through some of the points, none of the points, or all of the points. The key is to try to fit the line as closely as possible to the average trend in the data.*

Compare lines of best fit. Project **slide E**. Ask which line is a better fit to the average trend in the data. Students should say line C.

Say, *This trend line is also sometimes called the "best fit line" or "line of best fit". It helps us see that the data might be closer to a linear relationship than we suspected at first. If we collected and graphed additional data, this line also shows our best estimate of where we would expect that additional data to fall.*

Post a copy of *Example Line of Best Fit* on the Word Wall. Remember to cover this posting or remove it before your next class.



Instruct students to use an extra sheet of paper to cover the data points on their graph that represent when the object showed evidence of permanent deformation (these data points will be a solid circle or an "x"). Students should be looking at only the data points that are represented with an open circle on the graph.

Construct trend lines for the data that students collected. Tell students, *Sometimes data that don't look that linear end up looking much more so after we draw a best fit line. Let's see what that looks like for your data now.* Show **slide F**. Give students a minute to construct on *Deformation Results* the best fit line for their own data using a ruler (or wood stirrer) and a pencil or pen. Emphasize that students should only be considering the data points that are represented with an open circle on the graph.

Additional Guidance

Universal Design for Learning: Students with high interest in materials science or engineering may be curious to learn more about how other materials deform in response to contact forces. For those students, you can encourage them to test other materials or objects at home and bring in a graph to share with the class what they found. Other materials that are easy to collect data from include strips of cardboard and plastic rulers.

6. Navigation

3 MIN

Materials: *Deformation Results*

If time is short you may need to skip this step and related Turn and Talk.

Project **slide G**. Ask, *Do you think the trend in your data will be similar to or different from the trend in data from other groups? Why or why not?* Students will likely compare their graph to their partners in this discussion. Give students time to do this during this Turn and Talk and tell them they will have a chance to compare with all the other groups next time.

End of day 1

7. Navigation

5 MIN

Materials: *Deformation Results*

If you had time for students to do the Turn and Talk at the end of the previous class, say, *At the end of our last class you drew lines of best fit for your group's data and may have had time to compare it to one other group. Let's see how it compares to the rest of the groups.*

Groups discuss findings in a jigsaw activity. Project **slide H**. Ask all students who investigated a single wood stirrer to raise their hand. Count off by number and have them remember their number. Do the same for the students who investigated two wood stirrers. Do the same for those who tested single Styrofoam strips. Do the same for double Styrofoam strips.

Instruct students to relocate to meet with all the members of the class who have the same number as them. Give students about 3 minutes in these groups to compare and discuss what they notice in the different graphs.

Pause small-group discussion and ask 2-3 groups to share similarities or differences they noticed across all the graphs in the group and then say, *Just like the concrete beam data we saw earlier, scientists have studied other materials. Let's see how the patterns in our data compare to data collected by engineers when they tested different metals.*

8. Gather information.

12 MIN

Materials: *Results from other materials tests*, science notebook

Make predictions. Project **slide I**. Read the text on the slide. Point out that the compression machine described is shown in the photo. Have students turn and talk about their predictions. As students are doing this, hand out a copy of *Results from other materials tests* to each student.

Introduce the context of the reading. Emphasize that *Results from other materials tests* will summarize the results from the materials testing predictions they made with a partner. Project **slide J**. Instruct students to read and answer the questions on *Results from other materials tests* individually. Tell them that you want to collect this at the end of the period and that the last instruction in the reading is to update their individual Progress Trackers. Tell students that they should include anything they figured out from the lab and the reading that helps answer our lesson question when they get to that point as we are going to share our discoveries in a Scientists Circle after this.

Give students the remaining activity time to work on this individually.

Additional Guidance

Extension Opportunity: Students with high interest in materials science or engineering may be curious to learn more about how other materials deform in response to contact forces. For those students, you could provide an opportunity to research how the modulus of elasticity, yield strength, and ultimate tensile strength are related to things like the linear region of the force vs. deformation graphs, the elastic limit, and the breaking point on the graphs.

9. Add to our Progress Tracker.

15 MIN

Materials: science notebook

Lead a Consensus Discussion. Project **slide K**. Have students prepare a two-column Progress Tracker and record the lesson question in it.

Relocate in a Scientists Circle. Remind students that we first started researching this question by looking at slow-motion collision videos of cars, a baseball bat, and a golf ball. Ask students what additional sources of data we used to investigate this question since then. Students should recall four other sources of data. Help students agree on this list to add to their class Progress Tracker:

- slow-motion videos of collisions
- laser light reflected off a mirror on a piece of glass
- concrete beam load images
- force vs. deformation lab results (wood and Styrofoam)
- compression test results from engineers

*** Supporting Students in Developing and Using Patterns**
Students will have evidence of repeating patterns from their own investigations and from the investigations of other scientists. These should help them develop cause-and-effect relationships describing how contact forces can cause objects to break in some cases and not in others. This is an important sensemaking step in the progress toward student understanding of the anchor phenomenon.

Shift to co-developing a list of key ideas that we figured out from our work with these sources of data. Have students look back at what they wrote in their individual Progress Trackers for ideas. Use prompts similar to these, inviting students to contribute ideas and to work with the ideas that others contribute:

- *Who can suggest one idea we should add to our Progress Tracker about how materials respond when a force is applied to them?*
- *Is this true for all solids? How do we know?*
- *Can someone summarize an important idea about what it means when we say solids are elastic up to a point?*
- *If all materials are elastic up to a point, what is the difference between a rigid material like steel or glass and something that is more flexible?*
- *Does someone have an important idea about elastic limits or breaking points related to forces that we haven't included yet in our class Progress Tracker?*

Use follow-up prompts, such as *Do you agree?* and *Did anyone say the same idea in a different way?*, to encourage students to voice agreement on ideas.

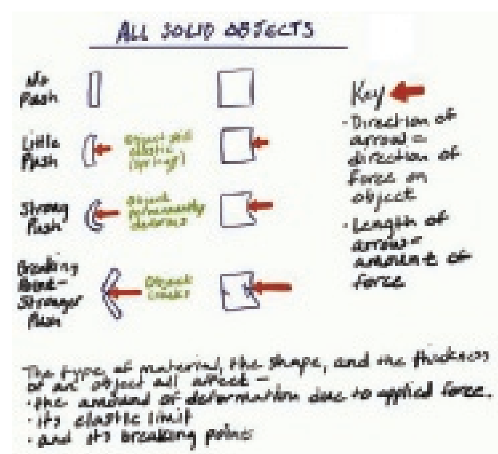
Key Ideas

Purpose of this discussion

- Summarize the main ideas about how solid objects respond to forces applied to them and how their elastic limits and breaking points are affected by the material they are made of, their shape, and thickness.

Listen for and have students make note of these ideas on their Progress Tracker:

- From previous lesson: All solid objects bend or change shape in a collision and when other contact forces are applied to them.
- All solid objects deform elastically when smaller amounts of force are applied to them; they will spring back to their original shape when this force is removed.
- How much a solid object deforms for a given amount of force applied to it is dependent on the type of material it is made of, its shape, and its thickness.
- Different objects have a different
    - **elastic limit =** the maximum amount of force or deformation they can withstand, beyond which they will deform permanently.
    - **breaking point =** the maximum amount of force or deformation they can withstand, beyond which they will crack or split apart.



In addition to a summary of the ideas listed in the "What we figured out" section, have students add to their Progress Trackers a visual representation of the ideas like the one shown here. Invite students to explain how these ideas help us answer our lesson question.* Use prompts like these:

- *Can someone summarize how these ideas help us explain why some contact forces damage objects and others don't?*
- *How could these ideas help explain why some collisions might cause damage and others don't?*

Listen for student responses related to the amount of force applied, the amount of deformation that it causes in the material, and whether the force exceeds the elastic limit of the object and/or its breaking point.

10. Arguing from Evidence

10 MIN

Materials: science notebook

Say, *We figured out a lot today about the deformation of materials due to forces, and we know that there is a force in a collision. Let's see if we can use these ideas to evaluate the claims that a company has recently made about creating an unbreakable screen for a phone.*

Argue from evidence. Project **slide L**. Ask students to use a piece of paper to quickly demonstrate and explain how this might be possible with a partner. Give students 2 minutes to talk. Look for students to fold or roll the paper without creasing it. Say, *In your notebooks, write an argument to share your thinking about this claim that there is an unbreakable and foldable phone. Support your argument using evidence from all our investigations so far.** At the end of this activity, collect science notebooks to review student responses.

Assessment Opportunity

Building towards: 4.B.2 Analyze and interpret graphical data (patterns) from tests of compression force vs. amount and type of deformation (temporary vs. permanent) to provide evidence that supports an argument that all objects behave elastically up to a specific limit beyond which permanent damage occurs (stability & change).

What to look/listen for:

- Students make claims and defend their thinking using evidence.
- Students are selecting and including multiple sources of evidence from their own and others' investigations.
- Students are organizing evidence so as to be persuasive in support of their claim.

What to do: Use questions to help students to organize and link evidence in support of their claim and to consider strategies for arguing persuasively for the validity of their claim. Here are some examples:

- How does your evidence support your claim?
- Does your claim rely on any inferences or assumptions?
- Do you have enough evidence to support your claim?
- Is there evidence to support a claim that is counter to your claim?

*** Supporting Students in Engaging in Argument from Evidence**

This activity supports students in making an argument that supports or refutes the advertised performance of a device using evidence from their own investigations and the investigations of other scientists. This is also an opportunity for students to begin to think about the criteria and constraints that are important in the design of materials used to protect fragile things, which will be addressed later in the unit.

11. Navigation

3 MIN

Materials: None

Motivate the next lesson. Say, *We've been thinking about how forces cause the shape of any object to change. And in an earlier lesson we argued that there are forces involved in a collision. Let's consider forces in collisions again. Think back to the slow-motion videos we analyzed. All of those situations we looked at involved one moving object and one motionless object before the collision. What about situations where both colliding objects are moving, like when a baseball bat and ball collide in a game of baseball? Does the bat hit the ball or does the ball hit the bat? What would be pushing on what? How about in the case of the golf club and golf ball?*

Display **slide M**. Give students time to discuss the questions on the slide with a partner and tell them we will explore this further in our next lesson. Remember to collect *Results from other materials tests*.

ADDITIONAL LESSON 4 TEACHER GUIDANCE

Supporting Students in Making Connections in ELA

CCSS.ELA-LITERACY.SL.8.1.C Pose questions that connect the ideas of several speakers and respond to others' questions and comments with relevant evidence, observations, and ideas.

CCSS.ELA-LITERACY.SL.8.1.D Acknowledge new information expressed by others, and, when warranted, qualify or justify their own views in light of the evidence presented.

Both of these ELA goals are the focus of the discussion in the Scientists Circle at the end of day 2 of this lesson when the class is working together to decide how to update their Progress Tracker. The focus on connecting questions, sources of evidence, what we observed, and key science ideas from other students in order to create an agreed-upon set of consensus ideas to add to the Progress Tracker relies on the first ELA goal above.

Supporting Students in Making Connections in Math

CCSS.MATH.CONTENT.8.F.B.4 Construct a function to model a linear relationship between two quantities. Determine the rate of change and initial value of the function from a description of a relationship or from two (*x, y*) values, including reading these from a table or from a graph. Interpret the rate of change and initial value of a linear function in terms of the situation it models and in terms of its graph or a table of values.

CCSS.MATH.CONTENT.8.F.B.5 Describe qualitatively the functional relationship between two quantities by analyzing a graph (e.g., where the function is increasing or decreasing, linear or nonlinear). Sketch a graph that exhibits the qualitative features of a function that has been described verbally.

Both of these math goals are a focus of the end of day 2 of this lesson when the class is working together to determine a trend line for a set of data (material deformation due to compression force). Students make a similar line for the data they plotted in the previous class and compare this to the lines of best fit made for data sets from other groups. Students also compare graphs of linear relationships for the elastic behavior of other materials and nonlinear regions in the graph as well. They interpret the graph to identify the point that the elastic limit of the object is reached and its breaking limit. They also interpret a table of values describing the slope of the line in a graph for the elastic behavior of the different materials as the ratio of material deformation in inches for a certain amount of compression force.

LESSON 5

How does changing the mass or speed of a moving object before it collides with another object affect the forces on those objects during the collision?

Previous Lesson

We planned and carried out an investigation into the relationship of contact force applied and the amount of deformation that occurs in different materials. We graphed our data and compared them to graphs from other materials tests. We developed a model to explain and represent the elastic and nonelastic behavior of all solid objects in response to varying amounts of force applied to them.

This Lesson

Investigation

2 DAYS

We carry out investigations to explore the strength of forces between two objects when they collide. We plan and carry out an investigation about how different speeds and masses of objects affect the amount of peak force on each object. We develop and use a model to represent the relationship between the energy of a moving object and the strength of the peak forces from a collision.

Next Lesson

We will look back at questions from our Driving Question Board and answer questions we have made progress on during Lesson Set 1. We will take an assessment to apply our science ideas to a new context and will determine we need to figure out what causes more damage and energy transfer during a collision—increases in mass or increases in speed.

Building Toward NGSS

MS-PS2-1, MS-PS2-2, MS-PS3-1, MS-ETS1-2, MS-ETS1-3, MS-LS1-8

What Students Will Do

5.A Plan and carry out an investigation and identify patterns in the data collected from the investigation to provide evidence that when peak contact forces on each object during the collision are equal in strength, the strength of those forces increases when the mass or the speed of the object that was moving before the collision increases.

5.B Develop and use subsystem models (free body diagrams) to represent how the peak contact forces on two different objects compare in a collision and how these are related to corresponding changes in the kinetic energy of a moving object before it collides due to a change in its mass or the speed.

What Students Will Figure Out

- Objects that make contact with each other apply equally strong forces on each other in opposite directions.
- Objects that collide apply an equally strong peak force (maximum force) on each other during the collision.
- A free body diagram can help represent the forces on the objects in a collision by considering each object separately.
- Increasing the speed or mass of a moving object increases its kinetic energy (KE).
- The more KE that objects in a system have, the higher the peak forces they can produce in a collision.

Lesson 5 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	**NAVIGATION** Share predictions about forces between objects in collisions.	A	
2	8 min	**EXPLORING FORCE INTERACTIONS WITH FINGERS**	B-C	
3	10 min	**INVESTIGATING WITH PUSH-PULL SPRING SCALES** Investigate how push-pull spring scales can help us see how the forces compare when two objects gently push or pull on each other.	D-E	*Comparing Forces on Two Push-Pull Spring Scales*, 2 5-N push-pull spring scales, 1 S hook, 2 sticky notes, 1 marker
4	12 min	**MAKING SENSE OF THE RESULTS AND TESTING FORCE INTERACTIONS BETWEEN DIFFERENT-STIFFNESS SPRINGS** Make sense of how push-pull spring scales can help us see how the forces compare when two objects gently push on each other.	F	1 5-N spring scale, 1 10-N spring scale, chart paper, markers
5	8 min	**PLANNING OUR NEXT INVESTIGATION** Plan an investigation to collect data for different collision conditions.	G-H	*Lesson 5: Independent, Dependent, and Controlled Variables*, chart paper, markers, transparent tape
6	2 min	**INTRODUCE THE READING** Orient to the reading that is related to finding out more about our fingers and other parts of our bodies that are able to detect forces applied to them.		*Reading: How does touch work?*
				End of day 1
7	5 min	**NAVIGATION** Share new insights from the reading. Review what investigation question each group is going to plan for and carry out and what led us to want to investigate these questions.	I	*Lesson 5: Independent, Dependent, and Controlled Variables*, *Object Interactions During a Collision*

Part	Duration	Summary	Slide	Materials
8	8 min	**PLANNING OUR INVESTIGATIONS** Identify variables for the investigation and prepare a data table to record the results.	J-K	*Lesson 5: Independent, Dependent, and Controlled Variables*, computer, projector, video (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)
9	10 min	**INVESTIGATING FORCE INTERACTIONS WITH DIFFERENT SPEEDS AND MASSES** Carry out the *Peak Force Collision Investigation*.	K	*Lesson 5: Independent, Dependent, and Controlled Variables*, impact goggles, Peak Force Collision Investigation
10	4 min	**INDIVIDUAL PROGRESS TRACKER UPDATE** Record and share what students figured out related to the lesson question in their individual Progress Tracker.	L	
11	15 min	**REVISE OUR CLASS CONSENSUS MODEL IN A SCIENTISTS CIRCLE** Develop a classroom consensus model to represent the results in terms of changes in the mass and speed of objects in the system and the resulting changes in the peak forces between the colliding objects.	M	colored pencils (black, red, blue, green, orange, and purple), Contact Force Interactions poster, chart paper, colored markers (black red blue green orange and purple)
12	3 min	**EXIT TICKET** Use the consensus model to explain how the strength of the forces between a falling phone and the ground would compare for three different scenarios.	N	scrap paper
				End of day 1
		SCIENCE LITERACY ROUTINE Upon completion of Lesson 5, students are ready to read Student Reader Collection 2 and then respond to the writing exercise.		Student Reader Collection 2: Bounce Back, Bend, Break, or Push

Lesson 5 • Materials List

	per student	per group	per class
Peak Force Collision Investigation materials		• 1 aluminum track secured to lab table with painters tape • 2 5-N spring scales attached to 2 carts with hook and loop fasteners • 1 twist tie collar on each spring scale plunger • 6 washers • 4-5 grams of modeling clay	

	per student	per group	per class
Lesson materials **Student Procedure Guide** **Student Work Pages**	• *Comparing Forces on Two Push-Pull Spring Scales* • science notebook • *Lesson 5: Independent, Dependent, and Controlled Variables* • *Reading: How does touch work?* • *Object Interactions During a Collision* • impact goggles • colored pencils (black, red, blue, green, orange, and purple) • scrap paper	• 2 5-N push-pull spring scales • 1 S hook • 1 5-N spring scale • 1 10-N spring scale	• 2 sticky notes • 1 marker • 2 5-N push-pull spring scales • 1 S hook • chart paper • markers • transparent tape • video (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**) • computer • projector • Contact Force Interactions poster • colored markers (black, red, blue, green, orange, and purple)

Materials preparation (45 minutes)

Online Resources

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Test the video link to make sure it is working. (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

Day 1: Spring Scale Investigations

- **Group size:** 6 groups of 3-4
- **Setup:** Set aside two 5-N push-pull spring scales and one 10-N push-pull spring scale and one S hook per group (these hooks are removed from the 5-N push-pull spring scales during the preparation described in *Spring scale and cart modifications and setup*).
- **Safety:**
  - Wear safety goggles or glasses during the setup, hands-on, and take-down segments of the activity.
  - Never eat any food items used in a lab activity.
  - Make sure all other fragile items are removed from the test area.
  - Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
  - Immediately pick up any items dropped on the floor so they do not become a slip/fall hazard.
  - Follow your teacher's instructions for disposing of waste materials. Wash your hands with soap and water immediately after completing this activity.

- **Storage:** All materials can be stored and reused indefinitely.

Day 2: *Peak Force Collision Investigation*

- **Group size:** 6 groups of 3-4
- **Setup:** See *Spring scale and cart modifications and setup* for directions on how to prepare the spring scales for day 2 of the lesson. The preparation of the spring scales and stations will take 30 minutes of the total preparation time for this investigation.
- **Safety:**
    - Wear safety goggles or glasses during the setup, hands-on, and take-down segments of the activity.
    - Never eat any food items used in a lab activity.
    - Make sure all other fragile items are removed from the test area.
    - Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
    - Immediately pick up any items dropped on the floor so they do not become a slip/fall hazard.
    - Follow your teacher's instructions for disposing of waste materials. Wash your hands with soap and water immediately after completing this activity.
- **Storage:** All materials can be stored and reused indefinitely.

Lesson 5 • Where We Are Going and NOT Going

Where We Are Going

In day 1 students figure out that it takes two objects to create a force and that forces come in pairs. When two objects touch, the first applies a force on the second and the second applies a force on the first. They then use spring scales to figure out that these forces have the same strength. Finally, in their investigations on day 2 students will figure out that during a collision the forces on each object are the same strength but opposite in direction, regardless of the speed of the objects and the masses of the objects in the collision. They will connect this outcome and the results that different groups produced to identify two causes for increases in the peak forces on both objects in a collision. One of these is an increase in the mass of a moving object, the other is an increase in the speed of a moving object, and both of these lead to an increase in kinetic energy of the object. The generalized understanding that students develop of the connection between energy and forces is that the more kinetic energy that objects have, the higher the peak forces they can produce in a collision with another object.

This lesson leverages student experience with planning an investigation elicited in the previous lesson. In that lesson, as in this one, they identified an independent and a dependent variable and variables to keep constant. A standard handout for planning an investigation and identifying variables was introduced for the first time in this grade band in the previous lesson. But that handout is one that they have used in prior grade units. The structure of that handout is the same as the one they are using in this lesson: *Comparing Forces on Two Push-Pull Spring Scales*. That should help make the investigation planning in this lesson a familiar process.

This lesson leverages students' prior thinking about systems elicited at the end of Lesson 2, where the class develops a system model similar to the one they are drawing now where one part of the system model was taking an energy perspective view of the phenomenon and the other part of the system model was taking a force interaction view of the phenomenon. You may want to refer to the Lesson 2 model at the end of this lesson. In future lessons you will want to refer to the system model you develop on chart paper at the end of this lesson.

In physics and engineering, a free body diagram is a graphical illustration used to visualize the applied forces on a body or object in a given condition. In such diagrams, the object is often represented as a box (or dot) and the forces acting on it are shown as straight arrows pointing in the direction they act on the body. Students will be introduced to standard conventions for representations for the external forces on that object that include the following:

- The direction of the force arrow indicates the direction of the force applied on the object.
- Differences in length of an arrow represent differences in the relative magnitude of a force.
- The tip of the arrow indicates the surface on which the contact force pushes.

There is an important reading for students to do before Lesson 6. It introduces students to how the sense of touch works and how this is connected to other structures that relay information to and from the brain. It is designed to be assigned as home learning at the end of day 1 of this lesson. In the reading students will be introduced to the structure of neurons and a substructure of these cells: axons. In Lesson 6, they connect the structure and function of axons to ideas they have developed about breaking point, contact forces, and kinetic energy to explain phenomena related to concussions in sports (and likely sources of it). This is one of many readings in the program that are spread across multiple units and are designed to target different parts of ideas related to MS-LS1-8.

Where We Are NOT Going

Students will not be using free body diagrams to represent coordinate systems since the grade-band focus of forces should be limited to the study of forces in one dimension.

We will not explore the amount of force required to change the motion of an object a certain amount. This will be explored in Lesson 7.

At the end of the lesson the class develops the idea that the more kinetic energy an object in a system has, the higher the peak forces it can produce in a collision with another object. The word “can” is an important qualifier since this relationship holds true for any collision where one object is motionless before the collision and the other object moves into it. It also holds for when two objects move toward each other head-on in a collision. The case where it doesn’t hold true is where both objects are moving in the same direction. For example, if both object A and object B are moving to the right and object A is catching up to object B, then any increase in the speed of object B that keeps the speed of object B less than that of object A will result in a collision between them that reduces the peak forces between them. This case is not one students will encounter in lesson activities in this unit and therefore not worth introducing.

LEARNING PLAN FOR LESSON 5

1. Navigation

5 MIN

Materials: None

Reintroduce the questions students were considering at the end of the last lesson. Say, *We've been using forces to explain deformation of objects in a collision or any time they make contact. So let's consider some of the cases we've looked at before using this force perspective.* Show **slide A**. Give students a moment to reread the text on the slide. Then say, *What did you and your partner predict about these two different cases? Were you in agreement or did you have different ideas?*

Share ideas about forces between objects in a collision. Anticipate some disagreement in students' responses. Encourage students to weigh in on the ideas that are shared so you can help students recognize that we are either not in agreement or we are uncertain about some of our predictions and need additional evidence to support alternate ideas.

Suggested prompts	Sample student responses
In each collision, what is doing the pushing and what is getting pushed?	*In the golf ball and golf club case, the force is only on the golf ball, not on the club. The club is the thing moving, so it is the only thing pushing. It is pushing on the golf ball.* *I think that both the golf club and the golf ball are getting pushed. Even if we can't see the club face bending, I think the stem of the club bends, and you would feel it getting pushed too. So I think both the ball and the club get pushed during the collision.* *In the baseball and bat case, you can feel the bat get pushed when you hit a ball. Sometimes the bat even breaks when a really fast pitch hits it, which must mean it got pushed beyond its breaking point.* *We saw both the ball and the bat get deformed in the video even when the bat was motionless and the ball was moving.*
So what happens when something like a phone falls and hits the ground and breaks? The two objects are the phone and the ground—what's pushing on what?	*The phone pushes on the ground.* *The ground pushes on the phone.*

Suggested prompt	Sample student responses
We figured out that for an object to break, it needs a force applied to it that deforms it beyond its elastic limit. So if you drop a phone and it breaks when it hits the floor, what could be pushing on the phone?	*I don't know!* *Maybe the floor?* *Maybe there is something we can't see pushing on the phone. Maybe it's the phone pushing on itself?*

Say, *It seems like figuring out what is pushing on what is something we need to resolve in order to explain why some things break and others don't in a collision. Let's look more closely at the interactions between two objects to see if we can figure out what is getting pushed in a collision. Maybe if we start by thinking about where the force is occuring during a collision, that will help us make progress on figuring out what is getting pushed and what is doing the pushing.*

2. Exploring Force Interactions with Fingers

8 MIN

Materials: None

Begin the exploration of force interactions between two objects. Say, *Let's start our investigations with our own built-in force sensors: our fingers.*

Show **slide B** and instruct students to follow the directions on the slide either on their own or in tandem with a partner if they want to do so. Don't take time to have students report out their results to the whole group yet though.

After everyone has completed these steps, which should take under 2 minutes, say, *We can use our fingers as a force sensor in a different way too.* Prompt students for an additional line of evidence we can use to determine that forces are being applied to any object.

Suggested prompt	Sample student response
What have we figured out will happen to the shape of any solid when we apply a contact force to it?	*It should deform.*

Suggest that we repeat the investigation again but that this time we look for deformation of our fingertips to determine which fingertip is getting pushed on when they make contact with each other.

Show **slide C** and instruct students to follow the directions on the slide either on their own or in tandem with a partner if they want to do so.* After everyone has completed these steps, which should take under 2 minutes, bring students together to discuss the results. Encourage students to look at what their fingers are doing again as they talk through these questions.

***Attending to Equity**
If you have a student with a physical disability who can't use fingers for this activity, revise the instructions to include the option to use other parts of their body, such as their knees or elbows, to feel forces. Or if they are not able to do any of these, they could do the activity with a partner at any place on their body that is appropriate for them to interact with and report that they can detect feeling (e.g., on their chin or forehead).

Suggested prompts	Sample student responses
Did you feel or see any push on your fingertips when they are not making contact with each other?	*No.*
Where did you feel a push or force on your fingertips when you tried this? On only one of the fingertips or both?	*I felt a push (force) on both my left and right fingertips.*
So, we only detect a force when our two fingers are touching, and we don't feel a force on either of them when they are not touching. How does this compare with where we saw evidence of deformation? Did we see only one fingertip deform or both when they touched each other?	*Both fingertip surfaces deformed.*
What was it that was applying the force on your left finger?	*Our right finger.*
What was it that was applying the force on your right finger?	*Our left finger.*
When you pushed harder with either fingertip how did that affect the amount of deformation on each?	*Both fingertip surfaces deformed more.*
What can we say about the direction of the forces on each finger? Are they in the same direction or in opposite directions?	*The forces seem like they are in opposite directions.*
How do you think the forces compare? Is one stronger than the other? What is your evidence?	*It's hard to say how the forces compare.* *It feels like they might be the same.* *The amount of deformation of my fingertips appears to be about the same, so maybe the forces are the same.*

3. Investigating with Push-Pull Spring Scales

10 MIN

Materials: *Comparing Forces on Two Push-Pull Spring Scales*, 2 5-N push-pull spring scales, 1 S hook, 2 sticky notes, 1 marker

Ask for ideas for how we could measure and compare the amount of force on objects that make contact. Say, *OK, so we can see evidence of forces on both objects that make contact with each other when we use our fingers as force detectors. But our fingers have some limitations in terms of comparing the amount of force on them. Though we can try to say whether we feel or see evidence of more or less force on them, they don't provide an exact measurement of the strength of the forces applied to them. What tools have we used in previous investigations to help us get a more-exact measurement of the strength of the force being applied to an object?* Students will say the spring scales.

Say, *Let's use those again to investigate how the strengths of contact forces compare. First we'll make some predictions for what the spring scales would show if we pushed them against each other or hooked them together and pulled them apart* . Distribute *Comparing Forces on Two Push-Pull Spring Scales*. Show **slide D**. Give students about 2 minutes to complete their predictions.

Alternate Activity

It is assumed that the photos on **slide D** will be adequate for helping students visualize what it will look like as they push the plunger ends of spring scales together and what it will look like as they pull the hooked ends of them apart. As an alternative, however, you could demonstrate how they will use the spring scales by holding up two 5-N push-pull spring scales as manipulatives. If you do this, put a sticky note labeled "A" on one and a sticky note labeled "B" on the other. This labeling is used in the student handout for the next investigation to refer to one spring scale vs. the other. Demonstrate bringing them toward each other, stopping short of actually making contact between them as you don't want to give away the results from the investigation they are about to do. Demonstrate looping an S hook through the opening on both twisted wire ends of the push-pull spring scales to do the pull investigation.

Have groups carry out the investigation steps summarized on slide E. It should take no more than five minutes for groups to get their spring scales and S hook, carry out their investigation, and record their results.

4. Making Sense of the Results and Testing Force Interactions Between Different-Stiffness Springs

12 MIN

Materials: 1 5-N spring scale, 1 10-N spring scale, chart paper, markers

Ask students to push their spring scales away from them to the center of the table while the class has a brief discussion.

Suggested prompt	Sample student response
What did your results show you about how the strength of the forces on each object compare when two objects make contact with each other? Are those forces the same strength or different? What evidence supports your claim?	*The forces are the same on each object. As we look across our data table, we see that the amount of force was the same in every single case.*

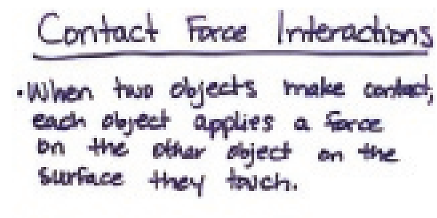
Help students summarize their findings across the two investigations.

Suggested prompts	Sample student responses
Can one object apply a force on another object without the other object applying a force back?	*No, it seems that if one object applies a force, the other object applies a force back. It didn't matter which one was doing the pushing in the cases of the fingers or the spring scales.*
So what then is the minimum number of objects you need in order to produce contact forces?	*It seems like you need at least two objects.*

Suggested prompts	Sample student responses
Did every object we tested deform when a contact force was applied to it?	*Yes.*
So if all objects are elastic up to a point and we know that even a small amount of force causes objects to bend some, why don't we see all objects visibly deform even when other things make contact with them?	*Some objects are stiffer than others.* *They deform such a small amount it is hard for us to detect it.*

Say, *Let's summarize what we've figured out.* Add this idea to a poster titled "Contact Force Interactions":

- When two objects make contact, each object applies a force on the other object on the surface they touch.



Introduce another case to consider. Say, *OK, so we know that all objects are elastic up to a point. When we made contact between two of the same type of object, two fingers or two spring scales, we found that they always pushed back or pulled back with equal strength on each other. But we also know that not all objects have the same level of springiness. Some deform a lot and some deform relatively little for the same amount of force applied to them. I have some spring scales that are like that too. Let's see how we can use those to explore how the forces compare when objects with different springiness push on each other.*

Make predictions. Say, *Let's get ready to use these different spring scales to test what would happen to the forces between any two objects when they make contact with each other, even when those objects have a different elasticity.*

Describe how a 5-N vs. 10-N spring scale deform when the same force is applied to them. Show **slide F**. Have students discuss predictions with their group, related to the question on the slide:

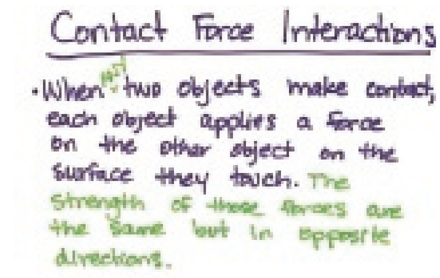
- How will the forces on each spring scale compare when you push them against each other? As they are doing this, distribute one 10-N spring scale to each group.

Test predictions. Once all spring scales are distributed, instruct students to take a couple of minutes to test their predictions they discussed from the previous question by pushing one 5-N spring scale against the 10-N spring scale.

After a couple of minutes, ask students to push their spring scales away from them to the center of the table while the class has a brief discussion. Refer to the Contact Force Interactions poster and ask if the statement on it was supported or refuted by the evidence collected from this investigation and what new ideas we can add to it.

Suggested prompts	Sample student responses
Earlier, we said that when two objects make contact, one object applies a force on another object and the other object applies a force back. Did that happen in this investigation even when the objects have different stiffness or elasticity?	*Yes.*
What did your results tell you about the strength of the forces on each object when two objects make contact with each other? Are they the same strength or different?	*The forces are the same on each object.*

Suggested prompts	Sample student responses
Are these forces in the same direction or in opposite directions?	*Opposite directions.*
So what new idea could we add to this poster we started about contact force interactions?	*The strengths of the contact forces are the same but in the opposite direction.*



Add this idea to the Contact Force Interactions poster by revising the statement that is already there. Then add the second statement to the poster:

- When any two objects make contact, each object applies a force on the other object on the surface they touch. The strengths of those forces are the same but in the opposite directions.

5. Planning Our Next Investigation

8 MIN

Materials: science notebook, *Lesson 5: Independent, Dependent, and Controlled Variables*, chart paper, markers, transparent tape

Motivate an investigation about whether these generalizations hold true with collisions. Say, *We've seen support for these ideas when we are holding the objects and applying a gentle push or pull to them. But do these ideas still hold true when we have collisions? Would the same equal forces on both objects happen when something is moving without us holding onto it and it collides into something else? Would changing anything about the moving object affect the forces between the two things when they make contact? Let's brainstorm some different collision conditions that we could possibly test with these carts.*

Show **slide G**. Give students a minute to orient to the setup shown on the slide and then think on their own about the question on the slide before discussing it as a class.

Suggested prompt	Sample student responses
What are some different collision conditions that we could possibly test with these carts?	*We could change* • *if one cart is moving or if both are moving,* • *if one cart is going slow or fast, or* • *if one cart is really heavy or light.*

Write student responses on a piece of chart paper and title it "How do forces on two colliding objects compare when we change . . .?". Guide students to think about 2 different cases: changing how fast the carts move and changing the mass of the carts.

Additional Guidance

Students may come up with changing the material; at this point, that is OK. Since they already looked at this by seeing what happens when they use two push-pull spring scales of different stiffness, you can argue that rather than immediately pursuing more investigations related to this variable in the next day of the lesson, we can return to it in future lessons (e.g., after Lesson 9) and now should try to make progress on the two variables they identified that we haven't investigated yet (mass and speed).

Say, *Let's start planning to collect data to investigate these two variables.* Ask students about what challenges they anticipate in data collection and investigation design.

Suggested prompt	Sample student responses
What are some challenges you anticipate in collecting data so that you can compare the amount of force on two different spring scales on two different carts when you collide the two carts together under these different conditions?	*It is going to be hard to read the spring scales during the collision because at least one of them will be moving before the collision.* *The collision happens so quickly that it will be hard to read the amount of force on both spring scales during that brief period of time.* *It could be hard to keep some things constant between different conditions. For example, it might be hard to ensure that we are colliding two carts together at the same speed if what we are trying to change is just the mass.*

Say, *These are all important challenges to consider in your investigation design, along with how much data you will need to collect to be certain of your findings, since we know when there are potential sources of error, more data make us more certain of what we can conclude. Since we have two different variables to investigate as a class, we need some groups to investigate how changing speed of a moving object before it collides with another object affects the forces on both objects during the collision, and we need other groups to investigate how changing the mass of a moving object before it collides with another object affects the forces on both objects during the collision.*

Write these two investigation questions at the bottom of the chart paper titled "How do forces on two colliding objects compare when we change . . .?" and label each with a letter:

A. How does changing the speed of a moving object before it collides with another object affect the forces on those objects during the collision?

B. How does changing the mass of a moving object before it collides with another object affect the forces on those objects during the collision?

Distribute *Lesson 5: Independent, Dependent, and Controlled Variables*. Show **slide H**. Assign half the class (three groups of 3-4 students) one of these questions to investigate and the other half of the class (three groups of 3-4 students). the other question. Instruct students to record the question they have been assigned on their handout and tape the handout into their notebooks.

6. Introduce the reading.

2 MIN

Materials: *Reading: How does touch work?*

Revisit using fingers as force detectors in prior investigation. Say, *You have used your fingers as force detectors today. Other places on us can detect contact forces against the skin too. Take a moment to touch the tip of your finger to the following: your forehead, your cheek, and your elbow. Pay attention to which of these seems most sensitive to being able to detect something touching it.* Give students a moment to do this as you distribute *Reading: How does touch work?* to each student.*

Summarize the focus of the reading and the related at-home investigation. Say, *In this reading you learn more about how our sense of touch works. I would like to collect these at the start of our next class to assess what you figured out.*

Additional Guidance

This is an important reading for students to do before lesson 6, as they will encounter diagrams representing the structure of neurons and damage to neurons as part of a related collision phenomenon that they will explain in the individual assessment related to memory loss due to concussions. In Lesson 6 (the next lesson), they connect the structure and function of axons to ideas they have developed about breaking point, contact forces, and kinetic energy to explain phenomena related to concussions in sports and likely sources of it.

End of day 1

***Attending to Equity**
Universal Design for Learning: The ideas presented in this reading can be conceptually challenging for some students, so having different modes for interacting with the reading will provide different ways to *access* the reading. Some students may benefit from having this reading available as an audio reading so they can listen as they read along on the handout. Other students may benefit from doing a partner reading. Some students may benefit from *expressing* their understanding by annotating and adding to the existing diagrams in the reading rather than drawing a new body system diagram from scratch as is prompted at the end of the reading.

7. Navigation

5 MIN

Materials: science notebook, *Lesson 5: Independent, Dependent, and Controlled Variables*, *Object Interactions During a Collision*

Follow up on the home learning assignment. If you assigned *Reading: How does touch work?* as home learning, ask students to turn and talk with a partner and summarize the most interesting idea they uncovered in the reading. Have students turn in the reading for you to review their responses.

Identify what we are planning to investigate today and why. Show **slide I**. Give students a minute to look at *Lesson 5: Independent, Dependent, and Controlled Variables* in their notebooks to find which investigation question their group is going to plan for and think about what they predict. Then report these in a whole-class discussion as well as what led us to investigate how the forces compare in collisions.

Suggested prompts	Sample student responses
What are different groups going to investigate?	*Some of us are going to investigate how changing the speed of a moving object before it collides with another object affects the forces on both objects during the collision.* *Some of us are going to investigate how changing the mass of a moving object before it collides with another object affects the forces on both objects during the collision.*
If you put one of the carts in motion and keep one stationary, which things in the system will have kinetic energy and which will not?	*The moving cart and the push-pull spring scale attached to it will have kinetic energy. The stationary cart and push-pull spring scale will not.*
So, for groups that are investigating changes in speed, how do we predict that will affect the forces on both cart subsystems during the collision?	*More speed will lead to stronger forces.*
For groups that are investigating changes in the mass of the moving object, how do we predict that will affect the forces on both cart subsystems during the collision?	*More mass will lead to stronger forces.*
With this predicted increase in the strength of the contact forces, will the forces on both spring scales still remain equal in strength like in our other investigations, or will they shift to being unequal?	*Accept all responses:* • *If the object is moving fast enough or has enough mass it will probably push harder on the object it collides with than that object will push back on it.* • *Maybe they still will be equal in strength, since that is what we saw in all of our previous investigations where we slowly collided two objects together.*
How is investigating these variables connected to the ideas we've developed so far about why things sometimes get damaged when they hit each other?	*All objects have an elastic limit and a breaking point. If the amount of force applied to an object exceeds this it can become permanently deformed (damaged).* *We need to understand how these force interactions change in collisions where the speed or the mass of the objects involved in the collision change.*

8. Planning Our Investigations

8 MIN

Materials: science notebook, *Lesson 5: Independent, Dependent, and Controlled Variables*, computer, projector, video (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

Introduce a peak force measurement device. Say, *Before you design the rest of your investigation, I have one other device you can use to help you record a measurement of the maximum amount of force on the push-pull spring scales during the collision. It's a simple twist tie collar that is wrapped on the plunger of the spring scale. Let me show you a video of how it works for a spring scale on a cart that collides with a brick.* Show **slide J**.

Show the video. Then ask students what they noticed happened to the twist tie collar and how this twist tie can help us measure the maximum amount of force applied during collision.

Suggested prompts	Sample student responses
What did you notice happens to the twist tie collar in the collision?	*It got pushed out a certain distance along the plunger beam.*
What would happen to the twist tie collar if a stronger amount of force were applied to the spring scale during the collision?	*It would get pushed further along the plunger beam.*
What would happen to the twist tie collar if a weaker amount of force were applied to the spring scale during the collision?	*It wouldn't get pushed as far along the plunger beam.*

Say, *This position of the twist tie collar can provide you a record of the maximum force or the peak force applied to the spring scale during a collision since each of the marks on the plunger beam corresponds to two of the marks on the newton side of the scale for the amount of force. Make sure to slide the collar back to the first mark next to the scale (which is zero), after you record the result from a collision. Remember to develop a plan with your group that includes a method for how to control for different variables and a data table to record the peak force on the push-pull spring scale for each condition you test.*

Review materials available and plan investigations. Show **slide K**. Say, *The materials you have available are shown on this slide. Discuss with your group the variables you need to change and measure for your investigation and record them on Lesson 5: Independent, Dependent, and Controlled Variables. Everyone in the group should prepare a data table to record your results on the next page of your notebook as well as a space to make note of any challenges or any sources of error you notice in your investigation. Everyone in the group should have impact goggles ready to put on before going over to the lab area to carry out your investigation.*

Assessment Opportunity

Building towards: 5.A Plan and carry out an investigation and identify patterns in the data collected from the investigation to provide evidence that peak contact forces on each object during the collision are equal in strength and the strength of those forces increases when the mass or the speed of the object that was moving before the collision increases.

*** Supporting Students in Engaging in Planning and Carrying Out Investigations**

In this investigation, students are now determining the independent and dependent variables they will be changing and keeping constant and recording them on *Lesson 5: Independent, Dependent, and Controlled Variables*. This is similar in structure to what they did in the previous lesson, but with less guidance. Students also plan their own data table. And they are asked to make note of any challenges or any sources of error they encounter in the investigation. This helps motivate the later need for calibrating the system being used to collect data in the investigation they carry out in lesson 7.

What to look/listen for

1. **Identification of a single independent variable:** mass or speed
2. **Identification of the following dependent variables:** the peak force measured on the push-pull spring scale on cart subsystem A and the peak force measured on the push-pull spring scale on cart subsystem B
3. **Identification of important variables to keep constant:** If students identified mass as the independent variable then they should identify speed as an important variable to try to keep constant. If students identified speed as the independent variable then they should identify mass as an important variable to try to keep constant.
4. **A data table** with results from at least two conditions tested (e.g., no additional mass vs. added mass or slower speed vs. faster)
5. **Peak forces measurements** and/or equalities or inequalities noted for both push-pull spring scales for each condition tested
6. **Results from repeated trials for each condition** (optional)
7. **Source(s) of error in the system** (optional)

What to do: You may want to have groups check in with you before moving to their labs to collect data. This would allow you to determine if the group members have properly considered 1-4 before carrying out the rest of the investigation. Once all groups are collecting data, you can then attend to whether groups are correctly recording data for 5 and 6. If time is short you could assign something related to 7 as a home learning assignment or extension opportunity, along with a question asking about ways to redesign the system to improve its reliability in terms of generating consistent results, eliminating more of the human error, and/or better controlling for speed if mass is the independent variable. This may lead students to propose ideas that are similar to what is in the procedure for the first investigation in Lesson 7 and can give you an opportunity to assess student thinking around engaging another part of the practice of planning and carrying out an investigation: revising an experimental design.

9. Investigating Force Interactions with Different Speeds and Masses

10 MIN

Materials: Peak Force Collision Investigation, science notebook, *Lesson 5: Independent, Dependent, and Controlled Variables*, impact goggles

Monitor lab work. Keep slide K projected.

Safety Precautions

Check that all students are wearing protective goggles.

Additional Guidance

If your school allows cell phones or has student tablets that can record slow-motion video and students suggest taking slow-motion video of the results, you could encourage them to try to capture that data too.

10. Individual Progress Tracker Update

4 MIN

Materials: science notebook

Update individual Progress Trackers. Show **slide L**. Ask students to record in their Progress Tracker this question and what they observed before we reconvene in a Scientists Circle to identify patterns in data and summarize what we figured out:

- How does changing the mass or speed of a moving object before it collides with another object affect the forces on those objects during the collision?

Give students time to record their discoveries.

Additional Guidance

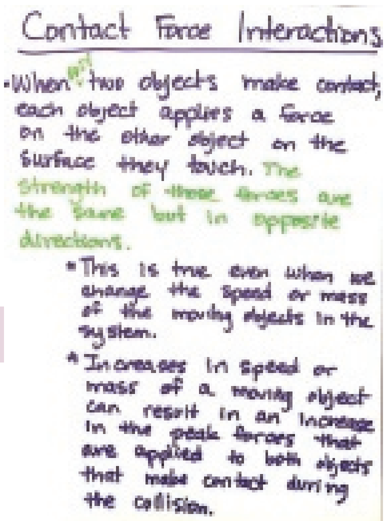
Go around and look at what students are writing in their Progress Trackers so you can determine if there are any lingering areas of disagreement or controversy about whether the forces are equal in every case tested. If so, you could use a suggested video as an additional source of evidence to resolve any remaining uncertainty. (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

11. Revise our Class Consensus Model in a Scientists Circle.

15 MIN

Materials: science notebook, colored pencils (black, red, blue, green, orange, and purple), Contact Force Interactions poster, chart paper, colored markers (black, red, blue, green, orange, and purple)

Gather students in a Scientists Circle. Display **slide M**. Bring the Contact Force Interactions poster to the circle. Ask students to share what they wrote in their individual Progress Trackers. You will incrementally develop a system diagram to represent and summarize the Key Ideas that are developed in this Consensus Discussion.



Key Ideas

Purpose of this discussion: Help students come up with another generalization that adds to the rule that the contact forces will be the same on each object in a collision regardless of changes in speed or mass. Connect the results of the investigation to changes in the kinetic energy of the objects and changes in the peak forces in the collision.

Look for these ideas (in bold below) to add to the Contact Force Interactions poster. Add these to the poster under the statements already included (the sentences in *italics* below):

* Supporting Students in Developing and Using Stability and Change

Add the term *free body diagram* to the Word Wall after the lesson and post the completed poster next to it. For now, focus on finishing the example on the poster of what free body diagrams look like.

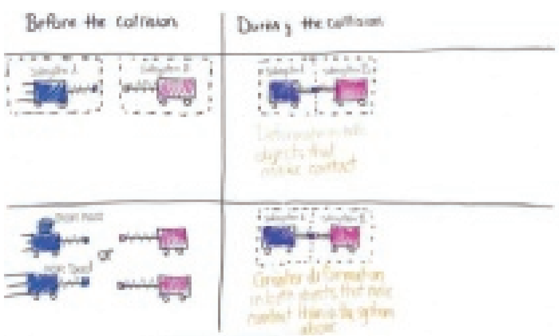
The introduction of free body diagrams here is designed to help students keep track of the forces acting on individual subsystems or objects within a larger system. In physics and engineering, the object is often represented as a box (or dot) rather than drawing something as elaborate as a cart

- *When any two objects make contact, each object applies a force on the other object on the surface they touch. The strength of those forces are the same but in opposite directions.*
    - **This is true even when we change the speed or mass of the moving objects in the system.**
    - **Increases in speed or mass of a moving object can result in an increase in the peak forces that are applied to both objects that make contact during the collision.**

Say, *Let's summarize what we noticed happened to the peak forces on both objects, the push-pull spring scales, when they collided after putting one of the subsystems they were attached to, a cart, into motion.*

Suggested prompts	Sample student responses
In the entire system we used for our investigation we collided two subsystems together. What were those two subsystems again?	*One push-pull spring scale attached to a cart was one subsystem and the other push-pull spring scale attached to a cart was the second subsystem.*
How does changing the speed of the cart subsystem before it collides with the other cart subsystem affect the peak forces on both objects that made contact (the push-pull spring scales) during the collision?	*The peak forces on both objects increase.* *But those forces remain relatively equal as this happens.*
How does changing the mass of the cart subsystem before it collides with the other cart subsystem affect the peak forces on both objects that made contact during the collision?	*The peak forces on both objects increase.* *But those forces remain relatively equal as this happens.*

Say, *Let's try to represent the relationship between these force pairs in a collision by showing what we know about the state of the system before the collision and during the collision when both objects in it experience peak forces.*



Draw a T-chart on two pieces of chart paper for representing the two subsystems in the system (the two carts with spring scales on them) as shown to the right. Color subsystem A blue and subsystem B red. Show the springs compressed during the collision and uncompressed before it. Add motion lines behind subsystem A before the collision to represent that it is moving and use longer motion lines to represent when it has more speed. This is the convention you established in Lesson 1. Show both carts with their springs compressed during the collision. Label the second system "Greater deformation in both objects that make contact than in the system above".

Suggested prompt	Sample student response
Are there any contact forces between subsystem A or subsystem B before they collide?	*No.*

Suggest that since there are no contact forces between the two cart subsystems until during the collision, and this is evident by there being no compression of the spring scales, it would make more sense to take a force perspective for

with wheels and a spring scale on top of it. But since this is the first such free body diagram students will have seen, make sure to keep a visual representation of the cart and spring scale in each diagram. You are introducing some standard conventions for representing the external forces on the subsystem or object, which include the following:

- The direction of the force arrow indicates the direction of the force applied on the object.
- Differences in length of an arrow represent differences in the relative magnitude of a force.
- The tip of the arrow indicates the surface which a contact force pushes on.

during the collision. Add "(force perspective)" in orange underneath the column head "During the collision" as shown in the image below.

Additional Guidance

In Lesson 8 students will argue that there are actually contact forces acting on the moving cart subsystem before the collision. These will include friction and air resistance. But the way the system is currently defined, excluding the surrounding air and surfaces the carts are rolling over, is making reference only to the contact forces between the two cart subsystems.

Transition to an energy perspective to describe the subsystems before the collision. Point out that subsystem A is moving in this system before the collision and subsystem B is not. Refer students to the energy perspective we took when we were keeping track of differences in motion in the model we made in Lesson 1. Ask students to identify how we referred to the difference in an object that was moving vs. not moving, using the energy perspective.

Suggested prompts	Sample student responses
Before you carried out your investigations, neither cart subsystem was moving. At that point does either subsystem have kinetic energy?	*No.*
If you hold one cart stationary and push and release the other cart to put it in motion, what parts of the system now have kinetic energy and which do not?	*The cart (subsystem) you put into motion has kinetic energy.* *The cart (subsystem) that is stationary does not have kinetic energy.*
What happens to the amount of kinetic energy the cart subsystem has when you increase its speed?	*It has more kinetic energy.*
What happens to the amount of kinetic energy the cart subsystem has when you put it into motion at the same speed as before but with more mass?	*It has more kinetic energy.*

Say, *We've already argued that there are no contact forces between subsystem A and subsystem B until they collide. But, we are arguing here that one of those subsystems, the one in motion, has kinetic energy and that the amount of kinetic energy it has changes based on its mass or its speed.*

Add "(energy perspective)" in green under the column head "Before the collision". Ask students which part of the system shown in the top left cell of the table should be labeled as having kinetic energy. Students should say subsystem A has kinetic energy and subsystem B does not. Label this in the model in green.

Ask students how we would describe the relative amount of kinetic energy of subsystem A when it is going faster. Students should say it has more kinetic energy. Ask the same about when the mass is increased. Again students should say it has more kinetic energy. Label this in the model in green.

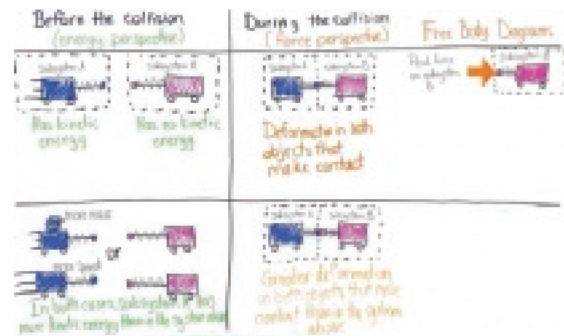
If students are uncertain about this, you can ask them to consider what has more kinetic energy, a single cart traveling at a certain speed or two carts connected together traveling at that same speed.

Transition back to a force perspective. Say, *Way back in Lesson 2 we argued that collisions can transfer energy, and that is still true, but all our new discoveries have been about the type of force interactions that are happening between these two subsystems during the collision. To capture what we have established, let's switch back to a force perspective to represent what we figured out about the contact forces during the collision.* Ask students how many of the objects/subsystems experience a force applied to them during the collision. Students should say two.

Introduce a convention for modeling forces on a single subsystem or object (free body diagrams). Say, *We could try to represent the forces on both objects in the system in the same diagram. But, since every place where there is contact, there will be two subsystems making contact and therefore there will be two forces between them, scientists and engineers usually switch to representing one single subsystem at a time in its own drawing. When they do that, they refer to each subsystem they draw as a* free body diagram. *It's called a free body diagram because in the diagram you show only a single object or body in the system, but you don't show any of the objects that are actually making contact with it. You free it up from the surroundings. But you still add in the forces that you know are acting on the object. Let's draw two free body diagrams now, one for each of these cart subsystems, to show how the forces on each compare.*

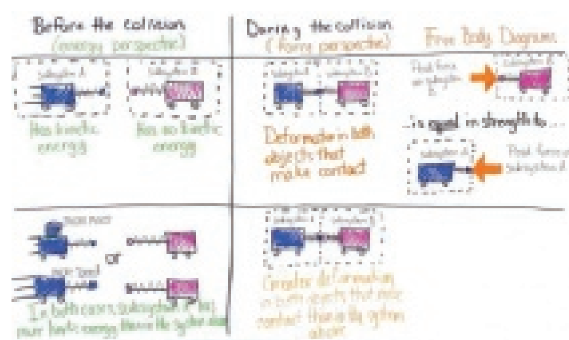
Add a final column labeled "Free body diagrams" to the right side of the chart paper. Ask students what is pushing on subsystem B during the collision. Students should say the end of the spring scale in subsystem A. Ask students to point in the direction that shows which way the force is pushing on subsystem B. Students should point to the right.

Say, *We can represent the direction of that force on subsystem B with a straight arrow going to the right, and we can show the tip of the arrow on the end of the spring scale plunger to indicate that this is the surface which the contact force is pushing. But let's make sure to draw that force arrow with a thicker line and arrowhead than the curved, thin arrows we used for representing energy transfer.* Draw subsystem B. Add an orange force arrow pointing to the right, touching the end of the plunger. Label this as "Peak force on subsystem B".



Ask students what is pushing on subsystem A during the collision. Students should say the spring scale in subsystem B. Ask students to point in the direction that shows which way the force is pushing on subsystem A. Students should point to the left.

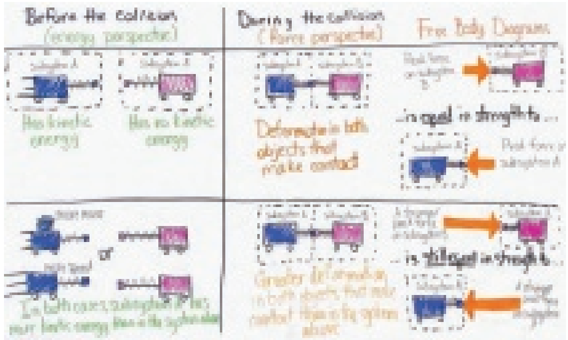
Ask how we can show that the strength of the force is the same on subsystem A as on B, but in the opposite direction. Students will say that we can use the same-sized arrow as before but facing the opposite way. Add the text ". . . is <u>equal</u> in strength to . . ." and then draw subsystem A below it. Add an orange force arrow pointing to the left, touching the end of the plunger. Make sure it's the same size as subsystem B's force arrow. Label this as "Peak force on subsystem A".



Ask students how we can represent what we know happens to the peak forces on these two subsystems when we have more mass or more speed. Students will say that you can show this by including larger arrows on both.

Ask whether those larger arrows should be different sizes from each other or the same size and why. Students will say that they should be the same size to show that the forces are still equal.

Add these representations and related labels to the model as shown to the right.



Qualify the relationship you established between the kinetic energy in the system and peak forces in a collision. Say, *This relationship holds true for any collision where one object is motionless before the collision and the other object moves into it. It also holds for when two objects move toward each other head-on in a collision.**

Additional Guidance

In the case where both objects are moving in the same direction, this relationship doesn't always hold. If both object A and object B are moving to the right and object A is catching up to object B, then any increase in the speed of object B that keeps the speed of object B less than that of object A will result in a collision between them that reduces the peak forces between them. This case is not one students will encounter in lesson activities in this unit and therefore not worth introducing.

Suggested prompt	Sample student response
Our model shows that the mass and speed of a moving object influence its kinetic energy. What does our model show the relationship is between the amount of kinetic energy in the system and the peak forces between the objects in the system when they collide?	*The more kinetic energy in the system the higher the peak forces will be between the objects in the system when they collide.*

12. Exit Ticket

3 MIN

Materials: science notebook, scrap paper

Refer to the model you developed to motivate testing the generalizability of these ideas in the upcoming assessment. Display **slide N**. Say, *Since peak forces could either be weak enough to not exceed the elastic limit of the objects in a collision or be strong enough to cause permanent damage, it seems like we now have a chain of cause-and-effect reasoning that we can use to explain why some objects get damaged and others don't in a collision. Let's try to use this model to explain some of our initial collision-related phenomena as well as some new phenomena. Next time, you will have* *a chance to do that as part of a more-formal Assessment Opportunity. You will be able to use your notebook and you can use the consensus model we developed on this chart paper too as reference. Before we do that more-formal assessment, let's complete a short exit ticket to check in on how you are thinking these ideas we developed would apply to something from our anchoring phenomenon.*

Alternate Activity

If time is short, you can administer this exit ticket as an entrance slip at the start of the next lesson. If you do that, it is suggested that you have students gather around the consensus model to kick off that task at the start of the next lesson.

Assessment Opportunity

Building towards: 5.B Develop and use subsystem models (free body diagrams) to represent how the peak contact forces on two different objects compare in a collision and how these are related to corresponding changes in the kinetic energy of a moving object before it collides due to a change in its mass or the speed.

What to look/listen for: Transferring the representations of the ideas developed in the class consensus model to a new context to explain a different phenomenon. The following ideas should be show up in students' responses:

- A: Students identify one or both objects.
- B: The forces would be equal in strength.
- C: The kinetic energy would be less.
- D: The forces would be weaker but still equal in strength.

What to do: Review student exit tickets before Lesson 6. These can serve as a useful benchmark for whether students are ready for more-formal and extended assessment in that lesson. If students struggle with the ideas on this exit ticket, revisit the consensus model at the start of next class and ask those students to co-articulate what the representations in it show and how these could be used to explain what is happening in another collision scenario (e.g., the ball and the bat or the golf club and the golf ball).

SCIENCE LITERACY: READING COLLECTION 2

Bounce Back, Bend, Break, or Push

1 **Materials That Stretch and Bend**
2 **Bottles and Baseballs**
3 **Collisions Up Close**
4 **Sharp and Pointy**
5 **Collisions with Fluids**

Literacy Objectives

✓ Summarize key points related to deformation and collisions.
✓ Organize related details about deformation and collisions.
✓ Translate text to visual/graphic representation of ideas.

Prerequisite Investigations

Assign the Science Literacy reading and writing exercise *after* class completion of this lesson group:

- Lesson 3: Do all objects change shape or bend when they are pushed in a collision?
- Lesson 4: How much do you have to push on any object to get it to deform (temporarily vs. permanently)?
- Lesson 5: How does changing the mass or speed of a moving object before it collides with another object affect the forces on those objects during the collision?

Instructional Resources

Student Reader Collection 2	**Science Literacy Student Reader, Collection 2** "Bounce Back, Bend, Break, or Push"
Exercise Page EP 2	**Science Literacy Exercise Page** EP 2

Literacy Activities

- Read varied text selections related to the topics explored in Lessons 3–5.
- Evaluate the reading selections according to provided prompts and criteria.
- Compare and contrast information gained from reading text with information gained from class investigation.
- Prepare an infographic in response to the reading.

Standards and Dimensions

NGSS

Disciplinary Core Idea PS1.A: Forces and Motion Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms; **PS2.A** For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law).

Science and Engineering Practice: Obtaining, Evaluating, and Communicating Information

Crosscutting Concepts: Patterns; Stability and Change; Structure and Function; Scale, Proportion, and Quantity

CCSS

English Language Arts

RST.6-8.2: Determine the central ideas or information of a primary or secondary source; provide an accurate summary of the source distinct from prior knowledge or opinions.

RST.6-8.10: By the end of grade 8, read and comprehend history/social studies texts in the grades 6-8 text complexity band independently and proficiently.

WHST.6-8.4: Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Core Vocabulary

Core Vocabulary: Core Vocabulary terms are those that students should learn to use accurately in discussion and in written responses. During facilitation of learning, expose students repeatedly to these terms. However, these terms are not intended for isolated drill or memorization.

breaking point	**deform**	**elastic limit**
newton	**peak force**	**pressure**

Language of Instruction: The Language of Instruction consists of additional terms, not considered a part of Core Vocabulary, that you should use when talking about any concepts in this exercise. Students will benefit from your modeling the use of these words without the expectation that students will use or explain the words themselves.

brittle	**deformation**	**elastic**
elastomer	**flexible**	**fluid**
malleable	**rigid**	

A Glossary at the end of the Science Literacy Student Reader lists definitions for Core Vocabulary and selected Language of Instruction.

1. Plan ahead.

Determine your pacing to introduce the reading selections, check in with students on their progress, and discuss the reading content and writing exercise. If you are performing Science Literacy as a structured, weekly routine, you might implement a schedule like this:

- Monday: Designate a ten-minute period at the beginning of the week to introduce students to the assignment.
- Wednesday: Plan to touch base briefly with students in the middle of the week to answer questions about the reading, to clarify expectations about the writing exercise, and to help students stay on track.
- Friday: Set aside time at the end of the week to facilitate a discussion about the reading and the writing exercise.

Exercise Page

EP 2

2. Preview the assignment and set expectations.

(MONDAY)

- Let students know they will read independently and then complete a short writing assignment. The reading selection relates to topics they are presently exploring in their Contact Forces unit science investigations.
- The reading and writing will be completed outside of class (unless you have available class time to allocate).
- Preview the reading. Share a short summary of what students can expect.
  - *First, you will read a comparison of materials that are elastic and those that are flexible.*
  - *Next, you'll read about how glass and plastic bottles compare when they collide with other objects and how baseballs and bats react when they collide with great force.*
  - *The reading that follows zooms in to show you what happens to the bonds between atoms and ions during collisions.*
  - *Then, you'll read about the collisions and forces involved in hooking a really big fish.*
  - *Finally, you'll read about collisions between liquids or gases and other liquids, gases, or solids.*
- Distribute Exercise Page 2. Preview the writing exercise. Share a summary of what students will be expected to deliver. Emphasize that Science Literacy exercises are brief. The focus is on thoughtful quality of a small product, not on the assignment being big and complex.
  - *For this assignment you will be expected to generate an infographic to summarize important and interesting ideas about objects, materials, deformation, and collisions.*
- Remind students of helpful strategies they can employ during independent reading. Offer the following advice:
  - *The reading should take approximately 30 minutes to complete.* (Encourage students to break reading into smaller sections over multiple short sittings if their attention wanders.)
  - *A good reading strategy is to scan through the collection first to see the titles, section headers, graphics, and images to see what the selections are going to be about before fully reading.*
  - *Next, "cold read" the selections without yet thinking about the writing assignment that will follow.*
  - *Then, carefully read the Exercise Page to understand the expectations for the writing part of the assignment.*
  - *Revisit the reading selections to complete the writing exercise.*
  - *Jot down any questions for the midweek progress check in class.* (Be sure students know, though, that they are not limited to that time to ask you for clarification or answers to questions.)

3. Touch base to provide clarification and address questions. (WEDNESDAY)

Touch base midweek with students to make sure they are on track while working independently. You may choose to administer a midweek minute-quiz to give students a concrete reason not to postpone completing the reading until the last minute. Ask questions such as these, and have students jot answers on a half sheet of paper:

Suggested prompts	Sample student responses
How does a bungee cord deform?	*It stretches and increases in length.*
How and why do glass and plastic bottles differ in how they behave in a collision?	*Glass is rigid, so the glass bottle breaks in a collision and cannot go back to its original shape.* *Plastic bottles can change shape quite a bit and return to their original shape after a collision.*
How close up would you have to be to show why salt is brittle rather than malleable?	*extremely close—close enough to show the bonds holding the salt ions together*
What unit is used to measure force?	*the newton*
What is an example of air colliding with a solid, a liquid, or a gas?	*solid—wind colliding with a sailboat's sail* *liquid—wind colliding with ocean water to make waves* *gas—two air masses colliding*

Ask a few brief discussion questions related to the reading that will help students tie the text content to students' classroom investigations.

Suggested prompts	Sample student responses
Some solids deform more than others. Based on what we learned in our investigations, are there any solids that do not deform? Explain.	*No, we learned in our investigation that even glass and concrete deform in collisions.*
What does an increase in the speed of the swing of a baseball bat do to the peak force of the collision with the ball?	*It increases the peak force.*
Why does a fishhook cause so much damage, even when you hardly pull on the fishing line?	*because all the force is concentrated in the very small point of the hook*

- Refer students to Exercise Page 2. Provide more specific guidance about expectations for students' deliverables due at the end of the week.
    - *The writing expectation for this assignment is to develop an engaging infographic summarizing five big ideas in this collection.*

Exercise Page

EP 2

- ◦ Engaging *means that that you will put some thought and planning into the layout and color choices and that you write in a style that will interest the reader.*
  - ◦ *Don't worry about producing a polished final product. Consider your work a draft.*
  - ◦ *Use your supporting details and drawings to show examples.*
  - ◦ *The important criteria for your work are that your summary statements are accurate and that you express yourself in ways that will engage the reader.*
- Answer any questions students may have relative to the reading content or the exercise expectations.

4. Facilitate discussion.

(FRIDAY)

Facilitate class discussion about the reading collection and writing exercise. The first selection discusses examples of materials and objects that deform in readily visible ways. The other four selections are more abstract in their discussion of deformation and collisions. Two discuss measurement, one explores molecular-level changes, and the final reading explains how air (which is invisible) collides with solids, liquids, and gases.

Pages 14–23 **Suggested prompts**	**Sample student responses**
What is the general purpose of the first selection, "Materials That Stretch and Bend"?	*It describes some materials that are elastic or flexible and explains the differences between these properties.*
How did you come up with a big idea from this reading for your infographic?	*Before I read it, I looked at all the pictures and thought about how they related to the title of the reading.*
What are the contact forces that cause deformation to each of the objects or materials shown in the photos?	*Bungee cord—the force of gravity pulls on the person, which pulls on the cord.*
	Latex—when you blow up a balloon, the force of air pressure stretches the latex.
	Rubber tire—when you drive over a rock, the rock pushes on the rubber and causes a temporary shape change.
	Silicone bakeware—you can twist it to change its shape and pop out the cake.
	Wood bow—when you pull on the bowstring, the string pulls the ends of the bow and makes it change shape.
	Guitar string—plucking (pull) or strumming (push) causes the string to change shape.
	Tendon—muscles contract, and that pulls on the tendon, which pulls on the bone.

Student Reader

Collection 2

SUPPORT—If you are using the recommended word envelope convention, check the envelope to see if it contains any words, phrases, or sentences that students need help understanding. Read key sentences aloud, and provide concise explanation.

Pages 14–23 **Suggested prompts**	**Sample student responses**
What is the general purpose of the second selection, "Bottles and Baseballs"?	*It explains how glass and plastic differ in their abilities to deform and how a baseball is just elastic enough to get a good collision with the bat.*
How does the second selection help you build knowledge on top of what you learned in the first selection?	*The first article describes some easy-to-see ways that materials and objects deform by stretching and bending. The second article explains that even hard, brittle materials are elastic.*
You read that a baseball deforms when it is hit by a bat. What about the bat? Does it deform? Explain.	*Yes, the bat deforms, too, but the amount it changes shape is small and so is hard to observe without special equipment.*
How does the graph help you understand what peak force *means?*	*If I think of* peak *as the top of a hill, I see on the graph that the greatest force lasts only a very short amount of time.*
What is the general purpose of the third article, "Collisions Up Close"?	*It explains what happens during some collisions to the chemical bonds holding atoms or ions together.*
How is the property called malleability related to the arrangement of atoms in metals?	*Metals are malleable because their atoms share electrons that move around a lot, making it easy for metals to be reshaped.*
What causes salt to be a brittle material?	*The type of bonds between the salt ions—when they are disturbed in a collision, the ions repel one another and salt shatters.*
What is the general purpose of the fourth article, "Sharp and Pointy"?	*It explains how fishing with a hook and line involves collisions and forces, and it also explains the advantages of steel over older materials used to make fishhooks.*
Where's the collision when someone catches a fish?	*The point of the fishing lure collides with the flesh of the fish.*
How are newtons useful when describing collisions?	*Since they are units of measure, they allow you to be precise about the amount of force applied in the collision.*
What is the general purpose of the fifth article, "Collisions with Fluids"?	*It explains how liquids and gases can be considered objects and therefore can collide.*
How does the fifth selection help you build knowledge on top of what you learned in the previous selections?	*In the previous selections, we learned about collisions between solids. In this selection, we learned that liquids and gases can also be involved in collisions.*

SUPPORT—Draw EL students' attention to the Vocabulary box where the verb *deform* is defined. Explain that verbs can become nouns by adding the suffix *-tion*, meaning the state, action, or process of. Pronounce the suffix for students as "shun," and then have students use *deformation* in a sentence. Point out that the "shun" suffix can also be spelled as *–ion* or *–sion* when it is used with other verbs.

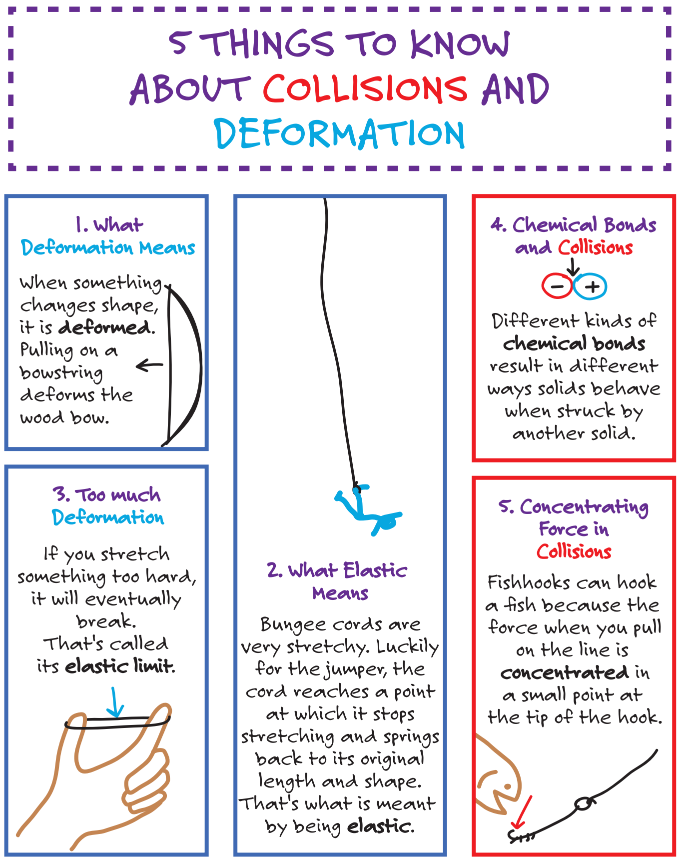
SUPPORT—Students are used to describing liquids they drink as "fluids" but may not be aware of the scientific meaning of this word. Explain that a fluid is any material that can flow, continually deforming in response to external forces. Therefore, gases as well as liquids are fluids, but solids are not.

Pages 14–23 Suggested prompt	Sample student response
Based on your investigations and discussions in Lesson 5, explain where forces are applied in the example of the sailboat on page 23.	*In addition to the air pushing the sail, the sail pushes back on the air with an equal force.*

5. Check for understanding.

Evaluate and Provide Feedback

For Exercise 2, students should, from a provided title and other scaffolding, develop an infographic to communicate an important idea about deformation or collisions from each of the five readings in Collection 2. Students' infographics should show that they took effort to produce a design that will attract readers, but don't score students on their drawing ability. A sample exemplary student product is shown but students may choose other colors, layouts, and facts that summarize the collection.



Use the rubric provided on the Exercise Page to supply feedback to each student.

Online Resources

EXTEND—If students wish to transform their draft infographics on paper into polished digital products, point them to appropriate design apps or websites. These tools have templates for varied layouts, colors, and text design, including animation options, and can be used with tablets or computers. Check the privacy policy of any tool before students use it to make sure it conforms with your school's internet-use policies.

LESSON 6

What have we figured out about objects interacting in collisions? How can we apply our new learning to answer questions about objects interacting in collisions?

Previous Lesson

We carried out investigations to explore the strength of forces between two objects when they collide. We planned and carried out an investigation about how different speeds and masses of objects affect the amount of peak force on each object. We developed and used a model to represent the relationship between the energy of a moving object and the strength of the peak forces from a collision.

This Lesson

Putting Pieces Together, Problematizing

1 DAY

We look back at questions from our Driving Question Board and answer questions we have made progress on during Lesson Set 1. We take an assessment to apply our science ideas to a new context and determine we need to figure out what causes more damage and energy transfer during a collision—increases in mass or increases in speed.

Next Lesson

We will carry out an investigation to determine how doubling the speed of an object vs. doubling its mass affects the amount of damage it does in a collision. We will use a computer simulation to collect data on the relationship among the mass, speed, and kinetic energy of an object. We will develop mathematical models of these relationships and use them to predict and explain how this could affect the amount of damage in a collision.

Building Toward NGSS

MS-PS2-1, MS-PS2-2, MS-PS3-1, MS-ETS1-2, MS-ETS1-3, MS-LS1-8

What Students Will Do

6.A Apply science ideas and use evidence to construct an explanation for how the amounts of peak force and energy transfer (cause) in soccer collisions result in instability in the brain (concussions, effect) due to sudden changes at the cellular level.

What Students Will Figure Out

We figure out these ideas:

- We have made progress on many of our DQB questions.
- We can apply our learning to answer questions about peak forces, damage, and kinetic energy of moving objects in soccer collisions.

Lesson 6 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	8 min	**NAVIGATION** Create a record of what we know so far about system interactions, forces, and energy in a collision.	A	What We Have Discovered poster, markers
2	12 min	**REVISIT DRIVING QUESTION BOARD QUESTIONS** Revisit the Driving Question Board and determine what questions we can now answer.	B-C	*Reviewing Our Driving Question Board*, Driving Question Board question list from Lesson 1, What We Have Discovered poster
3	20 min	**LESSON 6 ASSESSMENT** Distribute *Soccer Assessment*. Complete an assessment over interactions during a collision.	D	*Soccer Assessment*
4	5 min	**REVISIT QUESTIONS 6–7** Revisit questions 6 and 7 as a whole class.	E	

End of day 1

Lesson 6 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide** **Student Work Pages**	• science notebook • *Reviewing Our Driving Question Board* • Driving Question Board question list from Lesson 1 • *Soccer Assessment*		• What We Have Discovered poster • markers

Materials preparation (20 minutes)

Online Resources

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

- Create a list of all questions from the Driving Question Board (DQB) and make copies for all students.
- Create a poster on chart paper titled "What We Have Discovered".
- If using the slides, exchange the picture of the example DQB on slide B with an image of the actual class DQB.

Lesson 6 • Where We Are Going and NOT Going

Where We Are Going

This lesson provides an opportunity for students to revisit key ideas by taking stock of ideas learned in Lessons 1-5. We revisit the Driving Question Board and utilize the ideas to answer select questions from the beginning of the unit. Students do this before applying those ideas to a real-world soccer scenario in *Soccer Assessment*. This assessment targets the key DCI of PS2.A: For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger net force causes a larger change in motion.

Where We Are NOT Going

While students will be answering questions 6 and 7 on *Soccer Assessment* regarding whether a doubling of mass vs. speed would have a bigger impact on the kinetic energy of an object, these questions will not be assessed. This is because the quantitative effects of changing mass and speed on kinetic energy and peak force have not been addressed at this point in the unit yet. These ideas will be revisited in Lesson 7 during a student investigation of these factors and will be assessed later in Lesson 10. Although concussions affect various structures and regions of the brain in many ways, the impacts of a concussion on structures other than axons in the brain will also not be discussed in the assessment.

LEARNING PLAN FOR LESSON 6

1. Navigation

8 MIN

Materials: science notebook, What We Have Discovered poster, markers

Recall previous lessons. Project **slide A**. Say, *Last class we figured out that the peak forces are equal on each cart during a collision, regardless of the mass or speed of the individual carts. It's always an equal force, but in an opposite direction. We have also figured out a lot of other important ideas along the way! Let's look back and see what we have learned so far.*

Instruct students to look back at their Progress Trackers. Display the What We Have Discovered poster. Ask students to share what we have learned so far. Record student responses on the chart paper. Potential responses include the following:

- Sometimes objects get damaged in collisions; other times objects are not damaged.
- All objects have an elastic limit.
- The elastic limit is the point to which objects can spring back to their original position after a collision.
- If an object goes past its elastic limit, it will reach its breaking point.
- Energy is transferred in a collision.
- Energy transfer can make objects change shape.
- Contact forces cause a change in shape.
- All solid objects bend or change shape when any amount of contact force is applied to them.
- The amount an object deforms depends on the type of materials it is made of, how thick it is, and its shape.
- There are forces applied to each object when they are touching during a collision.
- The amount of the contact forces is equal on the objects that are colliding but opposite in direction.
- The peak forces can help determine if an object gets damaged.
- If the peak force is more than the elastic limit, the object will reach its breaking point.
- An increase in kinetic energy due to a speed or mass increase will increase the size of the peak forces between the objects in a collision.

Additional Guidance

The list of potential responses above is an example. It is not all-inclusive, and students do not need to come up with every idea presented in the example list but should have some ideas of energy and forces in a collision to help them think about their upcoming assessment.

If the ideas of energy are not presented, try asking questions such as these:

- What have we learned about energy in a collision?
- What does energy do in a collision?

- What does an increase in energy do to the forces on objects in a collision?

If ideas of forces are not presented, try asking questions such as these:

- What have we learned about forces in a collision?
- Are there any differences in the forces on objects when they are in contact with each other in a collision?
- What happens to the forces when the two objects in a collision touch?

As students review questions from the Driving Question Board, they will have an additional opportunity to review what we have learned through the lesson set as they apply those ideas to answer part of our Driving Question Board questions.

Say, *Wow, we have figured out a lot! I think if we look back at our Driving Question Board we may be able to make progress on answering some of our questions.*

2. Revisit Driving Question Board questions.

12 MIN

Materials: *Reviewing Our Driving Question Board*, Driving Question Board question list from Lesson 1, science notebook, What We Have Discovered poster

Review Driving Question Board questions. Project **slide B**. Distribute the Driving Question Board typed questions list you made from Lesson 1. If you plan to re-use these from class to class, then tell students not to mark on these handouts, but to make notes on the handout they will receive. Ask students to spend a moment looking over the list of questions.

Distribute the *Reviewing Our Driving Question Board* handout. Tell students they will spend some time working with a partner on identifying at least three questions they feel the class has made progress on and one question they feel they can answer from our Driving Question Board.* Go over the handout before allowing students to begin.

Assessment Opportunity

Revisiting the Driving Question Board provides a low-stakes moment for students to apply their ideas to real-world questions. As students are working, use this opportunity for formative assessment and listen to group discussions about what we can and cannot answer. Students should be able to answer questions regarding the items listed on the What We Have Discovered poster.

Students are also asked to record one answer using evidence for a question of their choice on the bottom of *Reviewing Our Driving Question Board*. Read over these answers as students are constructing them. If students are struggling, see the questions provided in the next section to also aid students in making connections between their key science ideas and a new scenario.

Circulate the room as students work in pairs to answer a question from the Driving Question Board. Listen carefully to student answers and listen for students to use science ideas to support their answers. If students are not using their science ideas to fully answer questions, use questioning to help students make the connection to their science ideas:

- What evidence do we have from past investigations that supports your answer?
- What patterns in past investigations and activities led you to that idea?

*** Supporting Students in Engaging in Constructing Explaining and Designing Solutions**

In Lesson 1, students engaged in the practice of asking questions when experiencing the anchoring phenomenon and brainstorming related phenomena. Over the course of recent lessons, students have developed science ideas that help to answer some of these questions. Revisiting the Driving Question Board provides an opportunity for students to review their questions about real-world phenomena and apply their science ideas to answer questions that did not have a clear answer in Lesson 1.

*** Attending to Equity**

Universal Design for Learning: As students read through their questions and think about which one they can answer with evidence, some students may find

- What patterns in data support your answer?
- Did we collect any other data or evidence besides the piece you cited that helps support your answer?
- Is there anything on our What We Have Discovered poster that helps you answer this question?
- Did you see something change in our system as two objects interact in a previous investigation or activity that supports this answer? What happened?

Additional Guidance

Some students may struggle with narrowing down the focus of a question. If students are having trouble coming up with answers for a related question on the Driving Question Board, ask students the following question:

Is the question you chose about the forces in a collision, the parts of the system, or energy transfer in a collision?

- If students answer that it is not about a previously visited topic, help them select a question that can be answered by our science ideas.
- If students answer that it is about a topic above, check to make sure that the question is asking something about these topics. If it is, then direct them to the poster with our discoveries and their Progress Trackers. Go through the items on the poster and in the Progress Trackers and help students identify which science ideas best help explain the answer to their questions.

Debrief the Driving Question Board. After about 10 minutes of work time, bring students back together as a whole group. Project **slide C**. Ask students the following questions.

- How many of you can now answer a question that we could not answer at the beginning of the unit?
- What questions do you now feel comfortable answering? What were your answers?
- Were there any questions about mass and speed that we couldn't answer yet? Which ones?

As students share their answers to questions from the Driving Question Board, it is possible that a student might share an incorrect answer. Do not automatically correct. Instead ask the class after each question if we agree or disagree with the answer. If students disagree with the answer, refer students to the What We Have Discovered poster and ask them to use our science ideas to justify if the answer is correct or incorrect.

Collect the copies of the Driving Question Board questions from students. Save these pages for students to use in a later lesson.

Say, *It seems like we can answer some of our questions on our Driving Question Board, but we still also have some questions we need to answer. Before we move on and try to investigate those questions, let's see if we can apply what we have learned so far to make sense of a new phenomenon.*

it easier to draw a representation or model of the answer to the question as they have been doing that in class. Allowing students to *represent* their answer in this way, for this low-risk assessment, will support multiple access points. If a student chooses to answer the question in this way, allow them to. Then if they answer a second question using the same modality, you could choose to follow up on their second drawing, by asking them to explain in writing what they modeled. In this way, the drawing provides the student something to write about. With practice over time, students will find more success writing arguments with evidence as they find confidence in their writing about models they have constructed using other modalities.

3. Lesson 6 Assessment

20 MIN

Materials: *Soccer Assessment*

Say, *I was reading and came across this scenario about headers being banned in soccer. How many of you know what a header is?* Listen for students' responses. If students do not know what a header is, explain that a header is when a player strikes the ball using their head.

Say, *There have been discussions to ban headers in youth sports because some people believe they are dangerous and can cause concussions. I thought we could dig into these ideas and see if we can explain using our science ideas if a header can actually cause a concussion and determine if there are other collisions that occur in soccer that can cause concussions as well.*

Distribute *Soccer Assessment*. Project **slide D**. Direct students to put their names at the top of the paper and read questions 1–5 together. Answer any clarifying questions students may have about the assessment.*

Once students understand what questions 1–5 are asking, read questions 6–7 of the assessment. Explain that the whole class will revisit the questions and answers from this section at the end of class. Tell the class to give their best guesses on questions 6–7 and to use experiences from real life and our prior investigations to help answer the questions. Questions 6–7 are not part of the assessment that we may be able to answer completely, but any ideas we have will help us determine our next steps as a class.

Ask students to complete *Soccer Assessment* on their own. Collect the assessment when students are finished.

Additional Guidance

Lesson 6 Assessment provides an opportunity for both summative and formative assessment. The science ideas built in Lessons 1–5 are applied in questions 1–5. Questions 6–7 are formative and will help gauge student understanding of the relationship between changes in kinetic energy, peak forces, and the mass and speed of a moving object.

Assessment Opportunity

Building towards: 6.A Apply science ideas and use evidence to construct an explanation for how the amounts of peak force and energy transfer (cause) in soccer collisions result in instability in the brain (concussions, effect) due to sudden changes at the cellular level.

What to look/listen for:

- Peak forces on the head and the ball are shown as the same during a header, both drawn in the diagram in question 1 and the selected answer in question 2a.
- Contact forces are applied to both objects and are always equal regardless of speed or mass in question 2b.
- A player hitting a nonmoving object should experience the least amount of peak force in questions 3a and 3b due to the moving player #84 having the same amount of kinetic energy in each collision. The masses and speeds of the other objects determine their kinetic energy before the collision, and the less total kinetic energy in the collision, the less the peak forces on each object during the collision.

*** Attending to Equity**

For question 5 of the assessment, students are asked to write an explanation supporting which type of head collision would potentially do more damage to the brain. Because students are synthesizing what they have figured out about collisions with new information they are reading during the assessment about the brain, offering students a choice in modality to demonstrate this synthesis provides equal access for all students. Some students may benefit from drawing a representation of the one collision they feel will do the most damage and labeling it to support why they chose the one they chose. As another alternative, some students may find more success explaining this orally through recording themselves and then turning in the recording, or presenting to the class, or presenting to you during an appropriate time in the classroom.

- Collisions with objects that are moving with a greater mass or speed in comparison with collisions that have lesser mass and speed will experience more peak force, as seen in the two potential answers for question 5.
- See *Soccer Assessment Key* for a more detailed analysis of what to look for in each question.

What to do: If after the lesson you find that students are struggling with equal and opposite forces with varying masses and speeds, revisit Lesson 5. First, revisit the handouts and data to make connections to a small ball and larger person from questions 1 and 2 on the assessment. Take time before lesson 7 to do this. Vary the mass and speed of different carts in collisions to simulate different collisions between the player and other objects in questions 3–4 and have students make note of their force observations as masses and speeds change on the back of the assessment. After reviewing the amount of force produced in each collision from the new demonstration, ask students to keep their observations out as they work through questions 5–6 again. You may also want to create a word bank with the key terms from Lessons 1–5 and refer students to the What We Have Discovered poster to make connections between our science ideas and the assessment questions.

Additional Guidance

When evaluating student ideas on this assessment, it may appear that some students may need to receive additional support in understanding the science ideas. As interventions are being conducted that are listed in the "what to do" area of the assessment guidance and students progress through Lessons 7–9, students may find value in the revision of their ideas. As the unit progresses, ask students to go back and revise their answers. Students can then use this document of evolving understanding to aid in their responses on the Lesson 10 assessment.

4. Revisit Questions 6-7.

5 MIN

Materials: None

Discuss questions about mass and speed. Say, *As I was walking around and looking at your assessments, it seems that we have different ideas about whether the mass of a moving object or its speed is a bigger factor contributing its kinetic energy and the resulting damage that it can do in a collision. Let's share some of our ideas about questions 6.* Present **slide E**. Ask students to share their ideas about question 6.

Suggested prompts	Sample student responses
What do we already know happens to the kinetic energy of a moving object when we increase its mass or its speed?	*It increases.*
And how does that increase in kinetic energy impact the peak forces produced in a collision between that moving object and a stationary one?	*The peak forces would increase as well.*

Suggested prompts	Sample student responses
If we were to compare one cart with double the mass and one cart with double the speed, would one have more kinetic energy than the other?	*Some students will likely say that the carts will have the same amount of kinetic energy because it is just doubled.*
	Other students may mention that the kinetic energy varies based upon the mass or speed changes, due to real-life scenarios such as a large car vs. a small car or a baseball being thrown lightly vs. a fast ball.
If you think one factor will increase the kinetic energy of the object and the resulting damage that it can do in a collision, which do you think is a bigger factor: the speed of a moving object or its mass and why?	*(Accept all student responses and ask students to provide real-world evidence to back up their answers.)*
	Students are likely to cite ideas related specifically to what would happen when you double the mass of a moving object vs. doubling the speed, as this specific comparison was something they were asked to brainstorm investigation ideas for in question 7.
How would damage in a collision be related to peak forces and the amount of kinetic energy in the system before the collision?	*More kinetic energy should result in higher peak forces, which should lead to more damage.*

Say, *This is really interesting. We can all seem to agree that increasing the mass or the speed of a moving object would increase its kinetic energy, which increases the peak forces in a collision. And we also agree this is related to the amount of damage in a collision. But where we have some disagreement is around whether doubling the mass of that moving object or doubling its speed would have a bigger effect on the kinetic energy of a moving object and the resulting damage it could do in a collision. So it seems like we have something we need to figure out to better understand these relationships. I look forward to reading through some of the ideas you wrote down in question 7 for investigations that could help us figure that out. Let's plan on investigating this question by pursuing some additional investigations and analyzing some additional source of data next time.*

How much does doubling the speed or doubling the mass affect the kinetic energy of an object and the resulting damage that it can do in a collision?

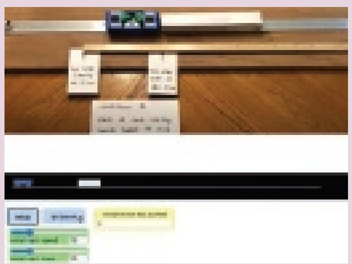
Previous Lesson

We looked back at questions from our Driving Question Board and answered questions we had made progress on during Lesson Set 1. We took an assessment to apply our science ideas to a new context and determined that we needed to figure out what causes more damage and energy transfer in a collision—increases in mass or increases in speed.

This Lesson

Investigation

2 DAYS



We carry out an investigation to determine how doubling the speed of an object vs. doubling its mass affects the amount of damage it does in a collision. We analyze data to determine how to quantify the relative change in the kinetic energy of an object. We use a computer simulation to collect additional data on changes in the mass and speed of a moving object and the amount of kinetic energy. We develop mathematical models of these relationships and use them to predict and explain how this could affect the amount of damage in a collision.

Next Lesson

We will develop a model to show where energy is transferred between the spring, cart, and box and how contact forces cause this energy transfer. We will use this to start brainstorming other places where contact forces may be causing energy transfer in the system.

Building Toward NGSS

MS-PS2-1, MS-PS2-2, MS-PS3-1, MS-ETS1-2, MS-ETS1-3, MS-LS1-8

What Students Will Do

7.A Construct, analyze, and interpret graphical displays of data collected from a computer simulation to identify patterns in the data, including a linear relationship between the mass of a moving object and its kinetic energy and a nonlinear relationship between the speed of a moving object and its kinetic energy.

7.B Construct an explanation based on quantitative relationships (scale) for whether decreasing the mass of a moving object or decreasing its speed would have a bigger effect on the peak forces produced in a collision between it and a stationary object and use these ideas to further explain why this would cause damage in some collisions but not others (effect).

What Students Will Figure Out

- In an investigation with multiple independent variables it is important to keep track of which variables are remaining constant and which are changing.

- The more kinetic energy an object has the more damage it can do in a collision.
- The more kinetic energy an object has the more you have to push against the direction of its motion to get it to stop.
- The kinetic energy of an object is directly proportional to its mass; the KE of an object is proportional to the square of its speed.

Lesson 7 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	**NAVIGATION** Recall what was figured out in the prior lessons.	A	chart paper, markers
2	12 min	**PLANNING OUR INVESTIGATION** Plan an investigation to collect data about the effects on kinetic energy of a colliding object when the mass or the speed of the object is doubled.	B	*Changes in Kinetic Energy: Investigations #1 & 2*, chart paper with investigation question, markers
3	14 min	**CARRY OUT AN INVESTIGATION ON DAMAGE FROM DOUBLING MASS VS. SPEED** Carry out an investigation to collect data about how doubling the mass and doubling the speed of an object affects the kinetic energy and the damage done in a collision.	C	*Procedure for Investigation 1*, *Changes in Kinetic Energy: Investigations #1 & 2*, Damage from Doubling Mass vs. Speed Lab
4	4 min	**ARGUE FROM EVIDENCE FOR WHICH FACTOR AFFECTS KINETIC ENERGY MORE** Argue from evidence about how the changes in the mass or the speed of an object affect the amount of kinetic energy that is transferred.		
5	12 min	**ANALYZING DATA FROM A QUANTITATIVE MEASURE OF ENERGY TRANSFER** Analyze videos of a spring-launched cart colliding with and pushing a box different distances depending on the mass and speed of the cart when launched.	D-G	*Changes in Kinetic Energy: Investigations #1 & 2*, computer, projector, three videos (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**)
				End of day 1
6	5 min	**NAVIGATION** Share patterns and predictions related to scaling up the mass or speed of a moving object and the relative increase in its kinetic energy.	H	*Changes in Kinetic Energy: Investigations #1 & 2*
7	5 min	**PLANNING FOR USING A COMPUTATIONAL SIMULATION** Orient to a computational simulation for collecting additional data on the relationship between changes in mass or speed and the kinetic energy of an object.	I	2 copies of *Graphing Kinetic Energy Relationships*, optional: 1 copy each of *Alternate: Graphing Mass vs. Kinetic Energy* and *Alternate: Graphing Speed vs. Kinetic Energy*, computer, projector, collision simulation (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

Part	Duration	Summary	Slide	Materials
8	15 min	**COLLECTING AND GRAPHING DATA FROM A COMPUTATIONAL SIMULATION** Use a computational simulation to collect additional data on the relationship between changes in mass and speed and the kinetic energy of an object. Graph the data collected.	J	2 copies of *Graphing Kinetic Energy Relationships*, optional: 1 copy each of *Alternate: Graphing Mass vs. Kinetic Energy* and *Alternate: Graphing Speed vs. Kinetic Energy*, computer, collision simulation (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)
9	10 min	**ANALYZE AND INTERPRET RESULTS OF OUR INVESTIGATION** Discuss the relationships in the graphs and tables for changes in mass and speed and the kinetic energy of an object.	K	calculator, 2 copies of *Graphing Kinetic Energy Relationships*, optional: 1 copy each of *Alternate: Graphing Mass vs. Kinetic Energy* and *Alternate: Graphing Speed vs. Kinetic Energy*, chart paper, markers
10	5 min	**INDIVIDUAL EXPLANATIONS** Construct an explanation for whether decreasing the mass of a moving object or decreasing its speed would have a bigger effect on the peak forces produced in a collision and use these ideas to further explain why this would cause damage in some collisions but not others (effect).	L	2 copies of *Graphing Kinetic Energy Relationships*, optional: 1 copy each of *Alternate: Graphing Mass vs. Kinetic Energy* and *Alternate: Graphing Speed vs. Kinetic Energy*, *Looking back: Explaining and predicting kinetic energy changes in the system*
11	5 min	**NAVIGATION** Generate new questions about where energy is coming from and going to in the spring-launched cart and box collision system.	M	3 sticky notes (3″ × 3″), marker, Interactions in the System poster from Lesson 2

End of day 2

Lesson 7 • Materials List

	per student	per group	per class
Damage from Doubling Mass vs. Speed Lab materials	• impact goggles	• 1 aluminum track with 1 10-N spring scale attached to it with hook and loop fasteners • 2 pieces of painters tape (4″ long each) to secure track to table top • 1 cart • 5 large washers • sticky putty (1 small-gumball-sized piece) • 2 fresh crackers • 1 brick • 2 sheets of blank paper	

	per student	per group	per class
		• 2 index cards (3″ × 5″) • calculator • timer	
Lesson materials **Student Procedure Guide** **Student Work Pages**	• science notebook • *Changes in Kinetic Energy: Investigations #1 & 2* • *Procedure for Investigation 1* • 2 copies of *Graphing Kinetic Energy Relationships* • optional: 1 copy each of *Alternate: Graphing Mass vs. Kinetic Energy* and *Alternate: Graphing Speed vs. Kinetic Energy* • computer • collision simulation (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**) • calculator • *Looking back: Explaining and predicting kinetic energy changes in the system* • 3 sticky notes (3″ × 3″) • marker		• chart paper • markers • chart paper with investigation question • computer • projector • three videos and collision simulation (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**) • Interactions in the System poster from Lesson 2

Materials preparation (30 minutes)

Online Resources

Review teacher guide, slides, and teacher references or keys (if applicable).

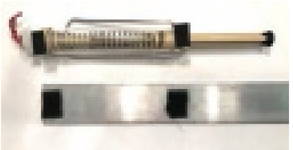
Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

If you anticipate that some students may struggle with setting up the axes and intervals for their graphs in investigation 3 using the blank graph on two copies of *Graphing Kinetic Energy Relationships*, make a copy of alternate handouts *Alternate: Graphing Mass vs. Kinetic Energy* and *Alternate: Graphing Speed vs. Kinetic Energy* for each of those students. In addition, you may wish to have extra copies of *Graphing Kinetic Energy Relationships* if students need to remake a graph or relabel axes.

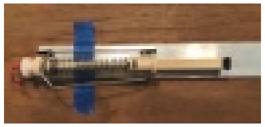
Test the videos you will use on day 1. (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**)

Test the simulation you will use on day 2. (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**). After it loads, press "setup" and the "go/pause" button to confirm that the model runs.

Day 1: *Damage from Doubling Mass vs. Speed Lab*



- **Group size:** Make groups 3-5 students
- **Setup**
  - Attach the fuzzy side of hook and loop fasteners stuck to each 10N push-pull spring scale per group. Attach two corresponding pieces of the rough side of hook and loop fasteners to one end of each track at the same distance apart as the fasteners on the spring scales. Remove the hook from the push-pull spring scale and replace it with a twisted piece of wire, as you did for the 5N push-pull spring scales in lesson 5.
  - Mount the 10N push-pull spring scale on the track. Tape the end of the track to a table top or to the smooth side of a 4 ft. long piece of laminate flooring.
  - Test the results produced by investigation 1, described on *Procedure for Investigation 1*, to ensure that the cracker does get damaged at least in condition C. The investigation as written assumes using a generic soda cracker, which cracks relatively easily. But there are other crackers that might crack even easier, such some brand name crackers with "crispy & thin" designations. You may want to try those in place of generic soda crackers. Fresh crackers damage more easily than stale ones, and high-humidity environments can prevent damage from occurring on the crackers. If this happens to you, there are two suggested options to remedy this:
    - One option is that you can boost the strength of the spring scale launchers by a factor of two by mounting two 5-N spring scales side by side on the track.



    - A second option is to swap in a stronger spring scale. If you do this, change by the same scale factor the corresponding amounts that students should use to launch their carts in conditions A, B, and C. For example, if you swap in a 20-N scale for a 10-N one, double the launcher force values from 5 N, 7 N, and 10 N to 10 N, 14 N, and 20 N in the student procedures for investigation 1 on *Procedure for Investigation 1*.

- **Safety:**
  - Wear safety goggles or glasses during the setup, hands-on, and take-down segments of the activity.
  - Never eat any food items used in a lab activity.
  - Make sure all other fragile items are removed from the test area.
  - Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
  - Immediately pick up any items dropped on the floor so they do not become a slip/fall hazard.
  - Follow your teacher's instructions for disposing of waste materials. Wash your hands with soap and water immediately after completing this activity.
- **Storage:** Discard used crackers in the trash. Unused crackers tend to go stale and do not crack as easily when this happens. Recycle used paper. All other materials can be stored and reused indefinitely.

Lesson 7 • Where We Are Going and NOT Going

Where We Are Going

In day 1 of this lesson students are introduced to the idea that experiments are not required to have only a single independent variable. Rather, the goal is always to keep careful records of which variables you intend to keep the same between different conditions and which you are not, as this can allow you to ensure that only one variable is changing between at least 2 conditions that you are testing. They then use this approach in the investigation they carry out. This deepens their understanding of the practice of planning and carrying out investigations.

In day 1 of this lesson students are reminded how quantitative data can be graphed to determine whether the relationship between the independent variable and the dependent variable is linear or not, in reference to the work they did in Lesson 4. They will engage in this sort of graphing and data analysis using the data they collect from a computer simulation on day 2 of this lesson. And the related mathematical thinking, where they determine scale factors to describe how much the *y* values and corresponding *x* values change between different conditions, will help prepare them for the type of quantitative data analysis and mathematical thinking they will need to do again in the Lesson 9 assessment. These experiences are helping students develop fluency engaging in the practices and using the related crosscutting concept (scale, proportion, and quantity) for meeting **MS-PS3-1:** *Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.*

There are multiple connections to make to the prior work students have done in math class regarding grade 6 and grade 7 CCSS math standards and to how you can help students develop and use CCC3: scale, proportion, and quantity related to the target lesson-level performance expectations.

To support using the crosscutting concept of scale, proportion, and quantity in this lesson you will help students calculate and use a type of ratio called a scale factor. Students will have encountered this concept before in math class when engaging in work around these two learning goals from the CCSS for mathematics in 7th grade:

- **7.G.A.1** Solve problems involving scale drawings of geometric figures, including computing actual lengths and areas from a scale drawing and reproducing a scale drawing at a different scale.
- **7.RP.A.2** Recognize and represent proportional relationships between quantities.

There are multiple connections to make to the work students will be doing in math class this year in grade 8 CCSS for math and to how you can help students develop and use SEP4 (analyzing and interpreting data) related to the target lesson-level performance expectations. Since students may develop and use these related concepts in math class later in this year, it is recommended you coordinate with the grade-level math teacher to determine when students will be doing such work so that you know what examples you can draw from or whether such work comes later in the year.

When students describe and compare the qualitative relationships between the mass of a moving object and its kinetic energy and the speed of a moving object and its kinetic energy they are developing and using ideas related to this current-grade math standard:

- **8.F.B.5** Describe qualitatively the functional relationship between two quantities by analyzing a graph (e.g., where the function is increasing or decreasing, linear or nonlinear).

When students describe and compare the quantitative relationships between speed of a moving object and its kinetic energy they are developing and using ideas related to this current-grade math standard:

- **8.EE.A.1** Know and apply the properties of integer exponents to generate equivalent numerical expressions.

Students will be working with squared relationships and cubed relationships in mathematics in 8th grade. They will be developing and working with expressions and equations that represent these relationships in symbols, particularly in the context of geometry, with their work on the Pythagorean theorem and determining the volume of cones, cylinders, and spheres.

Students start connecting new ideas about the relationship between forces applied to objects and changes in their kinetic energy. In investigation 1, they collect evidence that relates the amount of force needed to move an object to its mass and its change in speed, both of which determine that object's kinetic energy. In investigations 2 and 3, they collect evidence that objects with more kinetic energy need to be pushed more (over a longer distance) to get them to stop moving compared to objects with less kinetic energy.

Where We Are NOT Going

When students compare the relative amount of kinetic energy an object has by determining how far a cart can push a box it collides with and maintains contact with across a surface, they are using relationships that are part of the work-energy theorem. This theorem describes the quantitative relationship between the change in kinetic energy of an object and the force applied over a distance on that object. That quantitative relationship is not a focus of the unit and is beyond the grade-band learning targets. But, establishing a qualitative relationship between the net force applied to an object and how much this changes an object's motion (and the kinetic energy it has) is a focus of the unit. The source of that force (the friction between the box sliding over the track) is introduced in the next two lessons. But the fact that the strength of this friction force when the box is sliding is nearly constant is not addressed in this unit.

No attempt is made to assign units to the amount of energy an object has. The focus of this lesson is on the relative changes in amount of energy in terms of scale factors, which are unit independent. (See the **Online Resources Guide** for a link to the simulation that students use. **www.coreknowledge.org/cksci-online-resources**)

The focus of this lesson is not on developing an equation that relates the kinetic energy of an object to both its speed and its mass together. Such an equation (kinetic energy = ½ mass × velocity^2) is a high school learning target for PS3.B. In high school students will need to develop mathematical expressions that quantify the amount of energy in different parts of a system in order to develop and use models that account for the idea that total change of energy in any system is always equal to the total energy transferred into or out of the system. This lesson lays the groundwork for that equation but avoids going into that territory as it is well beyond the appropriate learning targets for 8th grade CCSS in mathematics as well.

1. Navigation

5 MIN

Materials: chart paper, markers

Summarize what we figured out so far. Say, *Let's remind ourselves what we figured out so far and where we think we need to head next.* Show **slide A**. Discuss the questions on the slide as a whole class. This can be a quick check-in on the set of ideas the class should already be in consensus about.

Suggested prompts	Sample student responses
How does increasing either the speed or the mass of a moving object affect its kinetic energy?	*Increasing either the mass or the speed of an object increases its kinetic energy.*
How do such changes affect the peak forces in a collision between that moving object and a stationary object?	*They increase the peak forces on both objects.*
How would such changes affect the amount of damage done in a collision? Why?	*It should increase the damage if the peak forces exceed the elastic limit.* *It should increase the amount of shape change or the amount of permanent deformation.* *It may lead to it breaking into pieces if the peak forces are greater than the breaking point of the object.*

Connect to the areas of disagreement in the predictions students shared last time and how we might go about investigating our competing predictions.

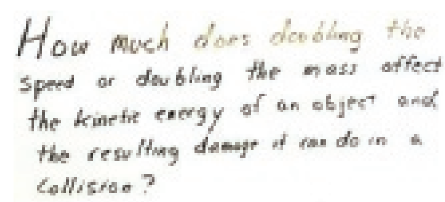
Suggested prompts	Sample student responses
Were we in agreement about whether doubling the mass or doubling the speed of a moving object has a bigger effect on the kinetic energy of a moving object?	*No.*
What were some of our different predictions?	*Some of us thought doubling the mass would have a bigger effect, and some of us thought doubling the speed would.* *(Some students may say that they would have the same effect.)*

*** Supporting Students in Engaging in Planning and Carrying Out Investigations**

Though students have planned other investigations before identifying the independent and dependent variables in an investigation they will benefit from seeing you develop an anchor chart for identifying the variables in this investigation. This is because the form of this investigation, where there is more than one independent variable to investigate and where students are going to change the value for more than one independent variable within a single investigation, is something they have not thought through in prior unit investigations. Since the procedure for this investigation is relatively complex and is already provided for students and this is the first example of a multi-independent variable approach to an investigation that students will have seen, this is not a place where it would be worth having students develop the investigation plan on their own. Instead, have students focus on contributing to the discussion in the next section about the variables in the investigation and ways to ensure that the spring-scale launch method can be calibrated to produce more-reliable results.

Suggested prompt	Sample student responses
How could carrying out an investigation where we compare the amount of damage done in two different collisions help us figure this out?	*If something with twice as much mass does just as much damage as something with twice as much speed, then they must have the same amount of kinetic energy.* *If doubling the mass results in more damage than doubling the speed, then increasing mass has a bigger effect on kinetic energy than doubling the speed.* *If doubling the speed results in more damage than doubling the mass, then increasing speed has a bigger effect on kinetic energy than doubling the mass.*

Say, *So if we weren't in agreement on our predictions related to this question, we will need some data in order to resolve this question about whether changes in mass or changes in speed have a bigger effect on the kinetic energy of a moving object and the damage it can do in a collision. Let's think through what we will need to do to collect that kind of data from an investigation using our cart system in order to try to answer this question.*



Write this question on chart paper:

- How much does doubling the speed or doubling the mass affect the kinetic energy of an object and the resulting damage that it can do in a collision?

2. Planning Our Investigation

12 MIN

Materials: science notebook, *Changes in Kinetic Energy: Investigations #1 & 2*, chart paper with investigation question, markers

Identify independent variables. Ask students what variables we will need to change in an investigation that answers the question recorded on the chart paper. Students should say the mass and the speed of a moving object.

Suggested prompts	Sample student responses
If we want to investigate how doubling the mass affects damage in a system, how would we measure its mass to ensure that we have made this change to the system?	*Using a digital scale.*
If we want to investigate how doubling the speed affects damage in a system, how would we measure or calculate its speed to ensure that we have made this change to the system?	*Use a timer and measure how far it goes in a certain amount of time.* *You can divide the distance the cart travels by the time it takes to travel that far to determine its speed.**

*** Supporting Students in Engaging in Analyzing and Interpreting Data**

A summary and related recall of what students did in Lesson 4 is an important one to do at this point in the lesson to remind students how quantitative data can be graphed to determine whether the relationship between the independent and dependent variables is linear or not. A summary and related also foreshadow something that students will argue for doing

Supporting Students in Making Connections in Math

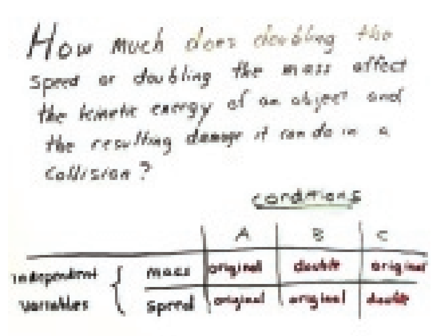
Working with unit rates and ratios is within the 6th and 7th grade Common Core Math Standards. By the beginning of 8th grade, students should be well versed in how to do this calculation. If students struggle with coming up with using unit rates to figure out how to measure speed, you may need to prompt them and support them in finding this calculation.

Introduce the idea that we can have more than one independent variable we want to investigate. Say, *In your experiences in science so far, you've had a lot of experience planning and carrying out investigations where only a single independent variable is changed at a time and you are trying to keep all other variables constant. This is often a very useful way to approach the design of an investigation since it tends to allow for more straightforward data analysis after you collect your data. This is particularly true when the data you are planning on collecting are quantitative and you want to graph it afterward to see if there are any interesting trends in it, such as whether the relationship between the independent and dependent variable is linear or not. You did something like this in Lesson 4 when you graphed the results from your force versus deformation investigations of wood stirrers and foam.*

Ask students which variables they put on which axis in that case and why. If needed, you can prompt students to look back in their notebook to *Deformation Results* where they graphed these data.

Suggested prompts	Sample student responses
What was the independent variable that you plotted values for along the x-axis of your graph? Was it the force you applied to the material or how much the material deformed?	*It was the force we applied to the beam.*
And then when you plotted the corresponding deformation on the y-axis, what sort of relationship did we see?	*It was linear.*

Continue explaining ways you can extend this approach to cases where you have more than one independent variable to investigate. Say, *In such cases like the one you just described from Lesson 4, you are able to see interesting trends in the data on a coordinate graph. As our investigations become more complex, we may sometimes find that we have more than one independent variable we need to change. In such cases it will be helpful to use a table to keep track of all the conditions we plan to test before we carry out our investigation so that we can identify which variables we are trying to keep constant between different conditions and which we are not. Let's create a table to help us keep track of this for our investigation.*



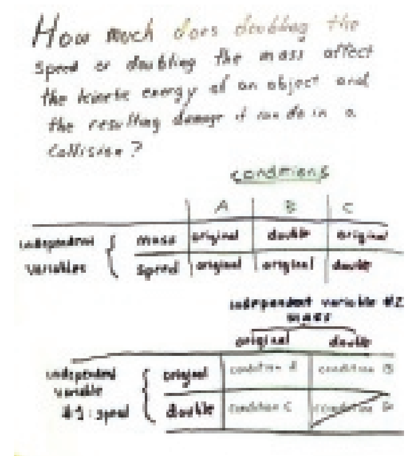
Add the following table to the chart paper on which you recorded the question being investigated.

with the data they collect from the computer simulation in day 2 of this lesson. And it also helps students understand that this is one important trade-off to consider in whether you design an investigation so that it has only one independent variable, which lend itself to mathematical models that can be derived from quantitative data, vs. designing the investigation so that it has more than one independent variable, which allows for comparing the relative impact of many different factors on a particular outcome.

* Supporting Students in Engaging in Planning and Carrying Out Investigations

In this investigation, students are provided a method for calibrating the system. This is part of building progression for this practice that comes together in lesson 12, where students carry out an investigation where they must figure out how to calibrate their system themselves for a control condition that all other groups are also using, and which they will use to gather data on a unique material they are testing and reporting out the results for.

Alternate Activity



The most common approach to investigating the effects of multiple independent variables in an experiment is called factorial design. In a factorial design approach, each level of one independent variable (which can also be called a factor) is combined with each level of the others to produce all possible combinations. In this context, doubling mass and speed would result in testing four conditions, the three outlined in the table below as well as a fourth, where both the mass and the speed are doubled. But in the context of the question students are investigating it doesn't make sense to test that fourth condition as well. This is what a factorial design approach for this investigation would look like, in case you want to demonstrate how to set up the additional table on the bottom of the poster to support this approach.

Use the suggested prompts below to have students think about what would be an important variable to keep constant between the different conditions and how one could measure it to ensure that this variable doesn't change.

Suggested prompts	Sample student responses
What would be an important variable to keep constant between conditions A and B?	*Speed.*
What would be an important variable to keep constant between conditions A and C?	*Mass.*
So how many variables are we changing between conditions B and A? Which one is it?	*One. The mass.*
How many variables are we changing between conditions C and A? Which one is it?	*One. The speed.*

Summarize that this is an example of building a table to keep track of the variables that we plan to change in each condition we plan to test and that this can help us recognize which variables are important to keep constant between each condition.

Distribute *Changes in Kinetic Energy: Investigations #1 & 2*. Instruct students to add this to their science notebooks to record their data in later.

Show **slide B**. Say, *Because you need a repeatable way to launch the cart at the same speed in condition B as you did in condition A, we are going to use a spring scale as a launcher. Let's think about how using a spring scale as a launcher can help us do that.*

Ask the following questions to raise issues related to the spring scale's use, the accuracy of the launch method, and the need to calibrate the system.

Suggested prompts	Sample student responses
If you push the cart against the spring scale and hold it at that position and then release it, what do you expect to see the cart do?	*It will move down the track.*
If you repeat what you did so that you push the cart against the spring scale just as far as the previous time and hold it at that position and then release it, how should its motion compare to the previous launch?	*It should move down the track in the same way.* *It should launch it at the same speed.*
What are some sources of error in this system that might cause it to not launch at exactly the same speed each time you release it from the same position as before?	*You might not be putting it at exactly the same position as before.* *You might have forgotten to zero the scale.* *Your fingers might get in the way of the release.* *There might be stuff on the track that gets in the way.*
What might be some sources of error when comparing the damage results?	*Crumbs might break off and they aren't part of the damage.* *You might lose track of the pieces that break off.*

Motivate the need for multiple trials and calibration for each condition based on these possible sources of error. Say, *The sources of error we've identified mean that before adding the damage target, the cracker, to the setup you will want to do a few trials to make sure you are confident that the speed of the launch isn't changing when you launch the cart from the same launch position every time.* * *Follow the procedure you will receive as it will describe this in more detail and will provide you steps on how to ensure that you capture all the pieces that might fall off the damaged object, the cracker, on a piece of paper under the brick. An image of this is shown on the slide.*

Alternate Activity

The cracker shown on the slide is a generic soda cracker. It cracks relatively easily. But there are other crackers that might crack even easier, such as some brand name crackers with "crispy & thin" designations. You may want to try those in place of generic soda crackers. If you do, you can swap in a new photo on this slide showing these new crackers in place of the default one on the slide.

3. Carry out an investigation on damage from doubling mass vs. speed. 14 MIN

Materials: Damage from Doubling Mass vs. Speed Lab, science notebook, *Procedure for Investigation 1*, *Changes in Kinetic Energy: Investigations #1 & 2*

Show **slide C**. Distribute *Procedure for Investigation 1* to students. Point out where in the room you want students to bring their damaged test objects (broken crackers and the index cards they were attached to with sticky putty and the papers used to collect the related debris from these crackers) at the end of their investigation, such as a back table or counter. Ideally this is a place students can either pull their chairs around or gallery walk along to be able to see the results. The purpose here is to provide them a space where everyone can do a quick glance over multiple sets of results quickly.

Safety Precautions

Remind students of safety considerations. Students should wear impact goggles during this investigation.

Monitor groups as they carry out investigation 1 following the procedure on *Procedure for Investigation 1*.

4. Argue from evidence for which factor affects kinetic energy more. 4 MIN

Materials: None

Argue for what the data show us. Gather students around the pooled class results (crackers on paper) or give them a couple minutes to do a gallery walk past all the collected results. Ask students to study the results and be prepared to make an argument for the answer to this original question based on our results:

- How much does doubling the speed or doubling the mass affect the kinetic energy of an object and the resulting damage that it can do in a collision?

Briefly discuss what the data tell us. Students will argue that doubling the speed of a moving object has a bigger effect on its kinetic energy, which causes it to have a greater amount of damage. Ask multiple students to weigh in on how the evidence supports this conclusion. Students should say that objects from condition C (doubling the speed) show more damage (more pieces and/or more cracks) in them than the same objects from condition B (doubling the mass).

Additional Guidance

Students may also note that this may be because the spring scale was pulled back further in condition C than in condition B. The lesson, as written, plans for students to start thinking about the qualitative relationship between changes in the maximum force from the launcher on the cart and the amount of energy transferred to the cart subsystem at the end of the lesson, rather than now. But if students spontaneously raise these noticings now during the investigation, follow up with additional questions in the moment to encourage additional reasoning about what they notice. Suggested prompts include the following:

- What does this tell you about the relationship between the force needed to move an object and its mass?
- What does this tell you about the relationship between the force needed to move an object and its speed?

- What does this tell you about the energy needed to get a stationary object to speed up twice as much as compared to getting an object to move at the original speed with twice as much mass?
- What does this tell you about which object might take more force to slow to a stop? (This question will help students anticipate the results from investigation 2.)

5. Analyzing Data from a Quantitative Measure of Energy Transfer

12 MIN

Materials: science notebook, *Changes in Kinetic Energy: Investigations #1 & 2*, computer, projector, three videos, collision simulation (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**)

Problematize the unanswered part of our question (quantifying "how much"). Say, *Though we can use our observations to argue that doubling the speed of a moving object has a greater effect on its kinetic energy than doubling its mass, our original question we were investigating was asking us "**How much** does doubling the speed or doubling the mass affect the kinetic energy of an object and the resulting damage that it can do in a collision?" Knowing how much of an effect one thing is having on something else can be answered through simply ranking our results to determine which thing has a bigger effect. But knowing specifically how much more is not something we can say unless we have some sort of way to quantify all the variables that are part of this question. We have a way to quantify the mass and speed of an object, but we don't have a way yet to quantify the amount of kinetic energy that object has.*

Introduce the potential advantages of a quantitative measure of kinetic energy. Say, *Finding a way to quantify how much kinetic energy an object has when we change its mass or its speed could provide us another tool for explaining why some things get damaged in a collision and others don't. It could also help us more precisely predict the amount of damage a moving object could do and maybe even give us ideas about ways to design solutions to prevent such damage from happening.*

Additional Guidance

This is the first time you will have raised the suggestion of designing solutions to prevent damages in a collision.

This is designed to start foreshadowing the direction of Lesson 9 and beyond in the unit.

Introduce a way to quantify the relative amounts of kinetic energy an object has. Say, *Scientists and engineers have developed different ways to measure and compare how much more kinetic energy one object has compared to another. One of those ways is to measure the entire distance over which two objects push on each other during a collision. This method involves colliding the moving object into a stationary object in such a way that the object that was moving remains in contact with the object it collided with and continues to push it along a surface until both have stopped moving, without causing any damage. Let's see what an example of this method looks like.*

Orient students to an example of such a measurement by showing a video clip. (See the Online Resources Guide for a link to this item. www.coreknowledge.org/cksci-online-resources)

Share likely sources of error in the system. Say, *We have seen the result from only one trial for one condition. If the person who made this video ran multiple trials for this one condition, using the same mass and speed each time, why might it be* *reasonable to still expect that there would be some amount of variation in how far the box is pushed in each trial? What might cause that variation?* Anticipated responses will reference sources of error students mentioned earlier in the lesson.

Say, *If we know there might be slight variation in the results, let's look for some really general patterns in the data from just one trial of the same three conditions we collected data on with our first investigation.*

Show **slide D**. Explain to students that you will show the video again and that they should prepare to record the related data for investigation 2 on *Changes in Kinetic Energy: Investigations #1 & 2*. Show the video for condition A again. (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**) Pause the video as needed. Give students a minute to record the related data.

Show **slide E**. Have students turn and talk about the questions on the slide.*

- When we double only the mass of the cart, how much further will it push the box?
- When we double only the speed of the cart, how much further will it push the box?

Alternate Activity

If time is short, you can pause the end of the first day of the lesson here on a cliff-hanger and tell students that we will collect the remaining data to check our predictions next time. If you do this, carry over the video analysis as well as the discussion of predicting the effects of tripling the mass or speed of the cart from slide G to the start of the next day.

Show and record data from the related videos. Show **slide F**.

- Show video 2. (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**) Give students a minute to record the related data in their investigation 2 data table on *Changes in Kinetic Energy: Investigations #1 & 2*.
- Show video 3. (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**) Give students a minute to record the related data in their investigation 2 data table on *Changes in Kinetic Energy: Investigations #1 & 2*.

These are all the values that students will end up recording in their data table for investigation 2:

	The same spring-scale launcher position (force in N) were used for these conditions as were used in investigation 1		
	Condition A	**Condition B**	**Condition C**
mass (g)	original: 64.2	double: 128.4	original: 64.2
average cart speed (cm/sec)	original: 93	original: 93	double: 186
distance the box was pushed before coming to a stop (cm)	10.2	20.4	40.5

Show **slide G**. Have students turn and talk about the questions on the slide. Give three minutes for this discussion:

- About how many times further did the box get pushed when the mass was doubled?
- About how many times further did the box get pushed when the speed was doubled?
- What does this tell us then about how much more kinetic energy the cart had in each case?
- Based on these patterns, make a new set of predictions:
    - If you tripled only the mass of the cart, how many times further will it push the box?
    - If you tripled only the speed of the cart, how many times further will it push the box?

Summarize that we will revisit these predictions next class to help us develop a mathematical model for quantifying the amount of kinetic energy an object has in order to be able to more accurately predict and explain what causes damage in some collisions and not others.

End of day 1

6. Navigation

5 MIN

Materials: science notebook, *Changes in Kinetic Energy: Investigations #1 & 2*

Show **slide H**. Cue students to look back at the results they recorded for investigation 2 on *Changes in Kinetic Energy: Investigations #1 & 2*. Discuss the questions on the slide.

Suggested prompts	Sample student responses
About how many times further did the box get pushed when the mass was doubled?	*About twice as far.* *Doubling the mass almost doubled the distance the box was pushed (compared to condition A).*
About how many times further did the box get pushed when the speed was doubled?	*About four times as far.* *Doubling the speed almost quadrupled the distance the box was pushed (compared to condition A).*
What does this tell us then about how much more kinetic energy the cart had in each case?	*It had double the kinetic energy when we doubled its mass, but it had four times as much kinetic energy when we doubled its speed.**
Based on these patterns, what predictions did you and your partner make about the following: If you tripled only the mass of the cart but kept its speed the same, how much further will it push the box?	*Tripling its speed would push the box nine times as far, but tripling its mass would push it only three times as far.*
If you tripled only the speed of the cart but kept its mass the same, how much further will it push the box?	*Tripling its speed would push the box six times as far, but tripling its mass would push it only three times as far.*

*** Supporting Students in Developing and Using Scale, Proportion, and Quantity**

To support using the crosscutting concept of scale, proportion, and quantity in this lesson you will refer to an idea from mathematics called a scale factor. Students will have encountered this concept when engaging in work around two related learning goals from the CCSS for mathematics in 7th grade. In this lesson, scale factors are used to describe the ratio of two different masses or two different speeds or two different amounts of kinetic energy. So for example, doubling any amount of mass would mean the ratio of the new mass to the old mass is 2, which is the scale factor. Halving the speed would mean the ratio of the new speed to the old speed is 0.5, which is the scale

Additional Guidance

Listen for this key idea, as helping students see that the relative increase in the distance the box is pushed is a measure of the relative increase in the kinetic energy of the object.

Connect to the idea of scale factors from math class. Say, *When you are saying you predict the new value compared to the old value will be 3 times more or 6 times more, you are describing the ratio of the new value to the old value as a scale factor.*

Motivate the need for a mathematical model. Say, *Notice that just one set of results is allowing us to make more mathematically precise predictions about the effects of scaling up the mass or speed by a different scale factor than 2. More data could help us develop an even more general mathematical model so that we can accurately predict how any change in the mass or change in the speed of a moving object would affect its kinetic energy. But to develop such a general mathematical model we are going to need more data.*

Problematize the limitations of the setup shown in the video. Emphasize that the track we used is only a meter or less long and that is true of the track we saw in the video too, so in our classroom space and with the limited supplies we have, we would run out of space and/or track if we keep increasing the kinetic energy of the cart and try to see how far it pushes the box.

Recall previous examples where students used computational simulations study. Say, *You've seen many cases in your previous science work when you were limited in your ability to study the entire system in some way. Sometimes when this happened, you switched to using a computational simulation to collect additional data. What were some of the systems you've studied where you've used a computational simulation to collect additional data about the system?*

Students will say things like these:

- particle collisions in *Cup Design Unit*
- absorption of food in the small intestine in *Inside Our Bodies Unit*
- photosynthesis in the chloroplasts of a leaf in *Maple Syrup Unit*
- orangutan ecosystem interactions in *Palm Oil Unit*

factor. Predicting and ultimately discovering how such changes affect the corresponding scale factor for kinetic energy (the ratio of the new kinetic energy to old kinetic energy) is the key discovery students will be making in the next investigation.

7. Planning for Using a Computational Simulation

5 MIN

Materials: science notebook, 2 copies of *Graphing Kinetic Energy Relationships*, optional: 1 copy each of *Alternate: Graphing Mass vs. Kinetic Energy* and *Alternate: Graphing Speed vs. Kinetic Energy*, computer, projector, collision simulation (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

Introduce the computational simulation students will use for investigation 3. Say, *Let's prepare to collect some additional data from a computer simulation that will allow us to further explore the relationship between the mass and speed of a moving object and its kinetic energy. First let's orient ourselves to the interface we will be using.*

Demonstrate a model run for the default simulation settings. Load the simulation. After the model loads, press "setup" and ask students what they notice. They will say that they see a cart, a track, and a box.

*** Attending to Equity**
Universal Design for Learning: If you have students who may struggle with setting up a graph, use *Alternate: Graphing Mass vs. Kinetic Energy* and *Alternate: Graphing Speed vs. Kinetic Energy* in place of the two copies of *Graphing Kinetic Energy Relationships*. These

Press "go/pause" and run the model. Ask students what they notice. They will say that the cart coasted down the track and ran into the box and pushed it a certain distance down the track.

Ask students, using the prompts below, how this simulation would allow us to collect the data we need to answer the question we have been considering.

Suggested prompts	Sample student responses
We were debating the effects of tripling the mass or speed of a moving object on its kinetic energy. How would this simulation allow us to answer this question?	*We could triple the mass and see how much further it pushes the box and we could do the same for tripling the speed.*
What is the relationship between how far the box moves and the kinetic energy of the virtual cart?	*The distance the box is pushed is a measure of the kinetic energy of the cart.*
In addition to tripling the mass or the speed, let's remember that we want to get a more complete sense of the mathematical relationship between changes in the mass or the speed and resulting changes in kinetic energy of a moving object. How many different data points do you think you'd need in order to determine what the trend is in a graph of your data?	*More than two.* *Four.* *As many as possible.*

Set up data collection tables. Show **slide I**. Distribute two copies of *Graphing Kinetic Energy Relationships* to each student as students are setting up their science notebooks to collect their data. Ask students why they will need two pieces of graph paper. They will say that they will need one for each data table or one for the effects of speed changes on kinetic energy and one for the effects of mass changes on kinetic energy.*

two alternate handouts have the axes labeled already for the students and will provide an *access* point for students who may not know how to do this yet or may struggle with this math skill.

8. Collecting and Graphing Data from a Computational Simulation

15 MIN

Materials: science notebook, 2 copies of *Graphing Kinetic Energy Relationships*, optional: 1 copy each of *Alternate: Graphing Mass vs. Kinetic Energy* and *Alternate: Graphing Speed vs. Kinetic Energy*, computer, collision simulation (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

Provide instructions for investigation and graph creation. Show **slide J**. Tell students that you want to collect their graphs at the end of the investigation as a formative assessment.

Cue students to launch the simulation on their own computers.

Monitor students during the investigation. Seven minutes into the investigation, cue students to start graphing their data if they have sufficient data in their data tables. This will leave eight minutes for developing the graphs, which some students will need, particularly since they are setting up the *x*-axis and *y*-axis and related intervals for both graphs on their own.

Assessment Opportunity

Building towards: 7.A Construct, analyze, and interpret graphical displays of data collected from a computer simulation to identify patterns in the data, including a linear relationship between the mass of a moving object and its kinetic energy and a nonlinear relationship between the speed of a moving object and its kinetic energy.

What to look for:

- the *y*-axis on both graphs labeled as “kinetic energy of the cart (measured as the distance the box is pushed)”
- the *x*-axis on one graph labeled as “mass” and the *x*-axis on the other graph labeled as “speed” or additional detail in the labels such as “mass of the moving object for a fixed speed” on the x-axis and “speed of moving object for a fixed mass” on the y-axis
- some major intervals marked on both graphs
- equal intervals used along each axis
- coordinate data points plotted on both
- a directly proportional pattern [linear and passing through (0,0)] in the mass vs. kinetic energy graph
- a nonlinear (quadratic) pattern curving upward from (0,0) in the speed vs. kinetic energy graph

What to do:

- If you see students assigning the mass or the speed to the *y*-axis rather than the *x*-axis, encourage them to reference their graph from Lesson 4 to identify which variable was their independent variable and which axis they put it on in that graph.
- If you see students trying to assign a label to every interval on their axes, suggest they take the approach they see on a metric ruler, where only major intervals are labeled, such as every 10 mm intervals, so that the in-between interval lines are assumed to be 1/10 of the value between each major interval.
- If you see students alter their *y*-axes scale to go by nonlinear intervals, point out that it’s easier to see linear vs. nonlinear patterns in coordinate graphs if the intervals for each axis are always equal along that axis and give students a new piece of graph paper to reset these up on.

9. Analyze and interpret results of our investigation.

10 MIN

Materials: science notebook, calculator, 2 copies of *Graphing Kinetic Energy Relationships*, optional: 1 copy each of *Alternate: Graphing Mass vs. Kinetic Energy* and *Alternate: Graphing Speed vs. Kinetic Energy*, chart paper, markers

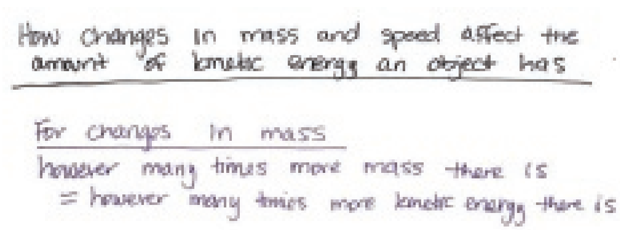
Show **slide K**. Give students 4 minutes with a partner to discuss the questions and do the calculations described on the slide. After this, discuss these questions as a whole class.

Suggested prompts	Sample student responses
Let's start with changes in the mass. What patterns do you notice in your graphs and tables?	*When the mass goes up, the kinetic energy goes up the same amount.* *The ratio of kinetic energy to mass is constant.*
If we think back to Lesson 2 and work you have done in math class, how could we describe this relationship between mass and kinetic energy.	*It is linear.*
A linear relationship is one way to describe this. We also can say it is "directly proportional" so that when one thing goes up, the other goes up the same.	
Let's see what this means: How much would the kinetic energy of a moving object increase if it had three times as much mass but the same speed?	*Three times as much kinetic energy.*
How about four times as much mass but the same speed?	*Four times as much kinetic energy.*
So are you saying that however many times more the mass is, that tells you how many more times kinetic energy the object has?	*Yes.*

Start an anchor chart **where you can summarize the relationships.** Say, *We can represent that relationship in a general way.* Add a title to the poster: "How changes in mass and speed affect the amount of kinetic energy an object has"

Under this add the following:

<u>For changes in mass</u>
however many times more mass there is = however many times more kinetic energy there is



*** Supporting Students in Engaging in Planning and Carrying Out Investigations**

Students should readily recognize that the relationship between mass and kinetic energy is directly proportional, as such a relationship is one they have encountered in graphs many times in Common Core mathematics since 6th grade. Recognizing the relationship between speed and kinetic energy as nonlinear will also be straightforward. But describing the change in kinetic energy as being related to the square of the speed of an object will be challenging. To help students see this, you may find it useful to talk about the scale factors related to the changes.

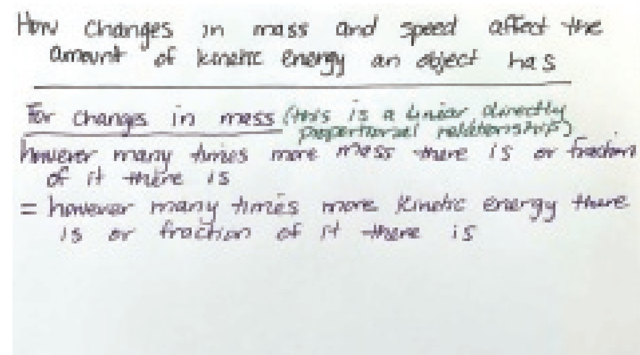
One useful way of talking about scale factors is the number that describes how many times larger a new number is compared to an old number. Another way to think about scale factors is as a ratio of a new value to an old value.

Students will have encountered working with squared relationships in 6th grade, in finding the surface area of a cube with sides of length *s*, and in 8th grade they will be working with squaring the side lengths of a right triangle in their work with the Pythagorean theorem. Coordinate with your math teachers to determine where your students will be at in their familiarity with thinking about symbolic relationships like this.

Ask about scaling down the mass.

Suggested prompt	Sample student response
What if we scale the mass down so that it has one-third as much mass. How much should the kinetic energy of the object change?	*It should be one-third of what it was.*

Suggest that what we wrote should also therefore have the phrase "or fraction of it there is" in it to show that we can scale the mass up or down and the amount of kinetic energy scales up or down accordingly. Add this phrase to the statement on the chart paper.



For changes in mass (*this is a linear, directly proportional relationship*) however many times more mass there is or fraction of it there is = however many times more kinetic energy there is or fraction of it there is

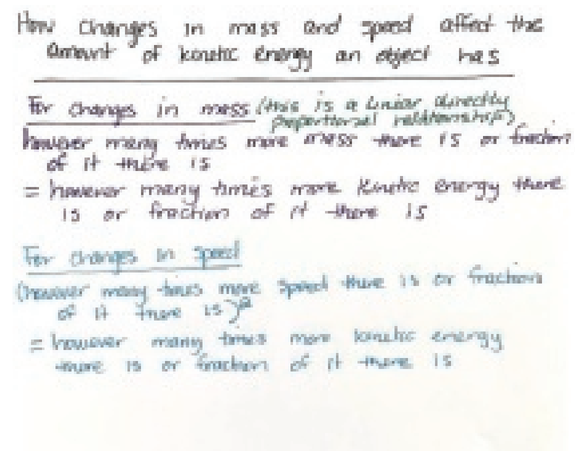
Shift to describing and representing the relationship between speed and kinetic energy. Say, *What about for the general relationship between speed and kinetic energy?*

Suggested prompts	Sample student responses	Follow-up questions
What about patterns about speed? What patterns do you notice in your graphs and tables?	*The more you increase the speed of an object, the more the kinetic energy of it goes up.*	*How does the graph help you see that?* *Can you show us what you mean?*
How much would the kinetic energy of a moving object increase if it had five times as much speed but the same mass?	*Twenty-five times as much kinetic energy.*	*How did you figure that out?*

Suggested prompts	Sample student responses
How about four times as much speed but the same mass?	*Sixteen times as much kinetic energy.*
So are you saying that however many times more the speed is, you can just take that number and square it and it tells you how many more times kinetic energy the object has?	*Yes.*
What if we scale the speed down so that it has one-third as much as before? How much should the kinetic energy of the object change?	*It should be one-ninth of what it was.*

Say, *We can represent that relationship in a general way.* Add this to the chart paper:

<u>For changes in speed</u> (*this is a nonlinear relationship*) (however many times more speed there is or fraction of it there is)^2 = however many times more kinetic energy there is or fraction of it there is



Additional Guidance

Extension opportunity: For students who find more-complex computational thinking highly *engaging*, you could give them an optional set of questions to consider to *express* their understanding of how combined effects of changing both the mass and the speed of an object would affect its kinetic energy. These possible questions include the following:

- How would the kinetic energy of an object change if it had three times as much mass and double the speed? (answer: It would have 12 times the kinetic energy as it did before.)
- How would the kinetic energy of an object change if it had half as much mass and half as much speed? (answer: It would have one-eighth as much kinetic energy as it did before.)
- How would the kinetic energy of an object change if it had ten times as much mass but moved 1/10th as fast? (answer: It would have 1/10th the kinetic energy as it did before.)
- How would the kinetic energy of an object change if it had sixteen times as much mass but 1/4th the speed. (answer: It would have the same amount of kinetic energy as it did before.)

10. Individual Explanations

5 MIN

Materials: science notebook, 2 copies of *Graphing Kinetic Energy Relationships*, optional: 1 copy each of *Alternate: Graphing Mass vs. Kinetic Energy* and *Alternate: Graphing Speed vs. Kinetic Energy*, *Looking back: Explaining and predicting kinetic energy changes in the system*

Celebrate that we have a way to quantify changes in kinetic energy. Say, *We made some real progress in figuring out a mathematical model that predicts how changes in mass versus changes in speed affect the kinetic energy of a moving object. But how does this help us more fully explain our anchoring phenomenon? Early in our work we said there is energy being transferred in collisions and that there are forces at work too. Let's try to unite those two perspectives more fully by thinking about all the places energy is getting transferred in our launcher system.*

Have students connect what we have figured out back to our anchoring phenomenon. Show **slide L**. Distribute *Looking back: Explaining and predicting kinetic energy changes in the system*. Emphasize that this is a formative assessment that you want to collect along with the graphs at the end of the period and that it focuses on the work we have done in this lesson. Give students the remaining time to complete the questions on *Looking back: Explaining and predicting kinetic energy changes in the system* and have them turn this in along with their graphs at the end of the period. Students may use their science notebooks as reference for this task. If time is short, assign this as home learning to turn in at the start of the next lesson or move it to the start of that lesson as an entrance ticket.

Assessment Opportunity

Building towards: 7.B Construct an explanation based on quantitative relationships (scale) for whether decreasing the mass of a moving object or decreasing its speed would have a bigger effect on the peak forces produced in a collision between it and a stationary object and use these ideas to further explain why this would cause damage in some collisions but not others (effect).

What to look for: On *Looking back: Explaining and predicting kinetic energy changes in the system*, any answers for questions 1 and 2 are acceptable. Many students will say that all three investigations were useful for question 1 (understanding the relationship between kinetic energy and damage). Most students will say investigation 3 in particular was most useful for question 2 (understanding the relationship between changes in mass and speed of a moving object and the amount of kinetic energy it has). Look for the following answers for questions 3 through 5:

- Q3): Reducing the mass of an object in half should reduce the kinetic energy to be half of what it was. Q4): Reducing the speed of an object in half should reduce the kinetic energy to be one quarter of what it was.
- Q5): We can predict how much more or less kinetic energy an object has when its speed or mass increases or decreases. These changes in kinetic energy would affect the peak forces produced in a collision. And if those peak forces don't exceed the elastic limit of the materials or objects that collide, then no damage will occur, but if they do exceed it then damage will occur.

What to do: If students incorrectly answer Q3 or Q4, have them refer to specific data they gathered from investigation 3 where the mass was halved and the speed was halved and have them calculate the related fraction of kinetic energy that resulted from this change, then have them use this calculation to support, refute, or revise their claim. If students don't connect to ideas about peak forces or elastic limit in Q5, ask them, *What ideas can you use about peak forces and the elastic limit of materials to develop a chain of cause and effect between how factors that affect kinetic energy like mass and speed are related to what is happening during the actual collision that helps explain why damage occurs or not?*

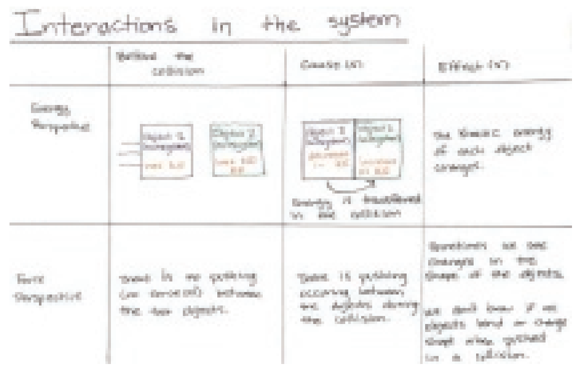
11. Navigation

5 MIN

Materials: science notebook, 3 sticky notes (3" x 3"), marker, Interactions in the System poster from Lesson 2

Unite two additional ideas related to energy transfer. Say, *You've just used the model we developed to explain how changes in the mass or the speed of an object would affect whether damage would result in a collision. This model uses kinetic energy of a moving object as an important way of predicting what will happen in a collision.*

Refer to the Interactions in the System poster you made at the end of Lesson 2 that summarized an energy perspective and a force perspective in a collision. Point out that this poster reminds us of how we initially argued that energy is transferred in collisions and that there are forces involved.



Problematize where the energy is coming from and going to in the system. Say, *But when we initially made this poster you provided a lot of examples of other systems where you tracked the energy flow across the system. You gave examples of phenomena that included things like cold liquid in a cup warming up or the formation of a hailstorm or the changes in the size of orangutan populations as a result of changes in the amount of accessible fruit trees in a forest ecosystem. In all these examples, we tried to track where the energy came from and where it went to in the system in order to better understand the phenomena.**

Problematize where the energy comes from in the system and where it is going. Say, *Thinking about where the energy is coming from and where it is going in a collision could help us understand and explain even more about collision-related phenomena. So let's consider an energy perspective for the entire system we used in this lesson with the cart, spring scale launcher, track, cracker, and box.*

Show **slide M**. Have students turn and talk to discuss the questions on the slide.

Save the last minute to have students make note of what new questions they have. If time permits you could have them write these new questions on sticky notes and add them to their science notebooks to share next time. Either way, suggest to the class that we will pick up our next lesson with this line of thinking by having students share some of the new questions that they are now considering about the entire system we used in the first two investigations in this lesson.

* Supporting Students in Developing and Using Energy and Matter

These are just a few examples of the kinds of phenomena you could reference from other units students have completed. Instead of repeating the examples here verbatim, cite the actual examples and how students described them that they mentioned in Lesson 2.

This cross-unit connection is an important one to make now to help recall how common and therefore how generalizable and powerful the use of the crosscutting concept is across the prior system models that students have developed in units: *The transfer of energy can be tracked as energy flows through a designed or natural system.*

Supporting Students in Making Connections in Math

Students calculate and use a type of ratio called a scale factor in this lesson. Students will have encountered this concept before in math class in one or both of these contexts:

- **7.G.A.1** Solve problems involving scale drawings of geometric figures, including computing actual lengths and areas from a scale drawing and reproducing a scale drawing at a different scale.
- **7.RP.A.2** Recognize and represent proportional relationships between quantities.

There are multiple connections between the work students will be doing in this lesson and the work they will be doing in math class this year (grade 8). These include the following:

- **8.F.B.5** Describe qualitatively the functional relationship between two quantities by analyzing a graph (e.g., where the function is increasing or decreasing, linear or nonlinear).
- **8.EE.A.1** Know and apply the properties of integer exponents to generate equivalent numerical expressions.

LESSON 8

Where did the energy in our launcher system come from, and after the collisions where did it go to?

Previous Lesson

We carried out an investigation to determine how doubling the speed of an object vs. doubling its mass affects the amount of damage it does in a collision. We used a computer simulation to collect data on the relationship among the mass, speed, and kinetic energy of an object. We developed mathematical models of these relationships and used them to predict and explain how this could affect the amount of damage in a collision.

This Lesson

Investigation

1 DAY

We develop a model to show where energy is transferred between the spring, cart, and box and how contact forces cause this energy transfer. We use this to start brainstorming other places where contact forces may be causing energy transfer in the system.

Next Lesson

We will conduct investigations to gather evidence to explain what other forces affect the kinetic energy of an object before a collision. We will develop claims using our evidence and provide and receive feedback with peers to synthesize our ideas. We will revise our model to show additional places in the launcher system where energy is transferred and how contact forces cause this energy transfer.

Building Toward NGSS

MS-PS2-1, MS-PS2-2, MS-PS3-1, MS-ETS1-2, MS-ETS1-3, MS-LS1-8

What Students Will Do

8.A Develop and use a model to identify other parts of the system the cart and box are making contact with or colliding into that could be producing contact forces on these subsystems, causing energy to be transferred to or from them as the box and cart travel down the track.

What Students Will Figure Out

- The more force you apply to an object the more that object speeds up.
- It takes more force to speed up a more-massive object the same amount as a lower-mass object.
- Potential energy can be stored in some systems when you change the shape or arrangement of parts in that system (e.g., a spring).
- Contact forces transfer energy between different objects or subsystems within the larger cart-launcher system.

Lesson 8 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	8 min	**NAVIGATION** Share new questions related to where energy was transferred from and to in the spring-scale cart-launcher and box system.	A	
2	5 min	**INDIVIDUAL EXPLANATIONS** Construct explanations about where and how energy was transferred from and to in the spring-scale cart-launcher and box system.	B	*Tracking energy transfers in our launcher system*
3	20 min	**DEVELOP A CONSENSUS MODEL OF ENERGY TRANSFERS IN THE SYSTEM** Develop a model in a Scientists Circle to show where energy was transferred from and to in the spring-scale cart launcher and how contact forces caused this energy transfer up to the point of the collision between the cart and the box.	C	*Energy transfers and contact forces in the launcher, cart, track, and box system*, colored pencils, Energy transfers and contact forces in the launcher, cart, track, and box system poster, colored markers, 13 prelabeled sticky notes (9 triangular with words, 2 square with red dots, and 2 rectangular with blue curved arrows).
4	7 min	**INDIVIDUAL MODELS** Develop and use a model to identify other parts of the system the cart and box are making contact with or colliding into that could be producing contact forces on these subsystems.	D	*Energy transfers and contact forces in the launcher, cart, track, and box system*, *Modeling other force interactions in the launcher, cart, box, and track system*, colored pencils, Contact Force Interactions poster from Lesson 5 (optional)
5	5 min	**NAVIGATION** Discuss other parts of the system that the box and cart are making contact with that could be producing contact forces.	E	4 index cards, 1 rubber band, *Investigating Surface Interactions*, *Investigating Interactions with the Air*, Energy transfers and contact forces in the launcher, cart, track, and box system poster, 18 prelabeled sticky notes (14 triangular, 2 square, and 2 rectangular).
				End of day 1

Lesson 8 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide** **Student Work Pages**	• science notebook • *Tracking energy transfers in our launcher system* • *Energy transfers and contact forces in the launcher, cart, track, and box system* • colored pencils • *Modeling other force interactions in the launcher, cart, box, and track system* • 4 index cards • 1 rubber band • *Investigating Surface Interactions* • *Investigating Interactions with the Air*		• Energy transfers and contact forces in the launcher, cart, track, and box system poster • colored markers • 13 prelabeled sticky notes (9 triangular with words, 2 square with red dots, and 2 rectangular with blue curved arrows) • Contact Force Interactions poster from Lesson 5 (optional) • 18 prelabeled sticky notes (14 triangular, 2 square, and 2 rectangular)

Materials preparation (20 minutes)

Online Resources

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Make a copy of *Investigating Surface Interactions* and *Investigating Interactions with the Air* for each student as you may find that most students elect to do both rather than just one of the investigations as home learning.

Before class begins, make a poster titled "Energy transfers and contact forces in the launcher, cart, track, and box system" so that it mirrors the top portion of *Energy transfers and contact forces in the launcher, cart, track, and box system* and includes only time 0 through time 3.

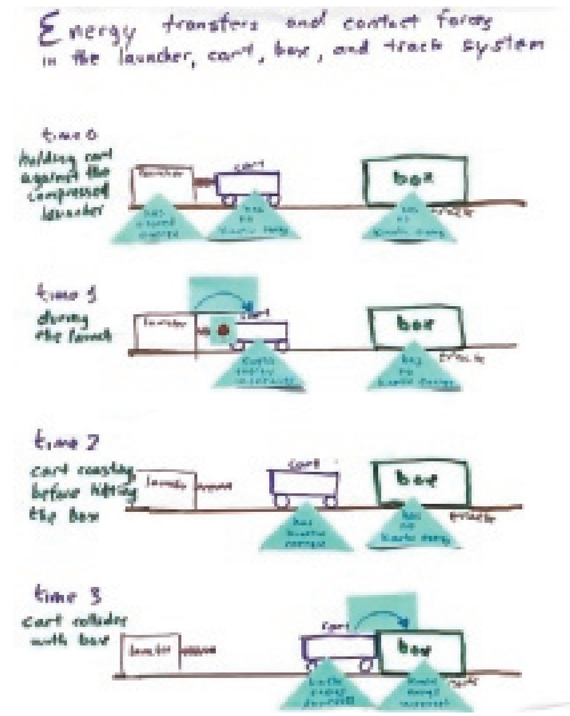
Cut 9 sticky notes (3" x 3") in half along the diagonal, keeping the sticky backed halves. Label the diagonal pieces as shown in the photo on the next page. Take 2 uncut sticky notes (3" x 3") and label them with a curved blue arrow. Cut out 2 rectangles out of another sticky note that are approximately 1" x 1.5" and draw a red circle on each. This will make 13 total sticky notes.

Position all of these sticky notes on the poster ahead of time to make sure you can lay them out in the positions shown. Remove these sticky notes and set them to the side to reuse between classes so that you can interactively place them on the poster with your next class.

Prepare sets of 4 index cards and a rubber band wrapped around them for each student to take home.

Lesson 8 • Where We Are Going and NOT Going

Where We Are Going



Students learn that contact forces are causing energy transfer through the launcher system, and they generalize this idea as contact forces can cause energy transfer in any system. Students will use this idea in the Lesson 9 assessment and will revisit it in future units, including *Unit 8.2: How can a sound make something move? (Sound Unit)*.

They learn that potential energy can be stored in some systems when the shape or arrangement of parts in that system is changed (e.g., a spring). This is the first introduction to stored (potential) energy in the unit sequence. Students will expand and deepen their understanding of this form of energy in *Unit 8.3: How can a magnet move another object without touching it? (Magnets Unit)*, where they figure out that the field between objects stores potential energy in the field and exerts distance forces on the objects that produced the field.

Students brainstorm additional sources of matter the box and cart are in contact with that may be producing contact forces on them to account for where the energy in the system is transferred to explain why those objects eventually stop moving. They are likely to generate two main sources of matter in the system: the track and the air. These two subsystems will be ones they investigate further in their home learning and in investigations in the next lesson. The at-home investigations and those in lesson 9 will help them identify interactions with the air (air resistance) and sliding surface friction as two important contact force interactions causing energy to transfer from the cart and box to their surroundings.

Where We Are NOT Going

Students will not identify other energy transfers to the surroundings such as those due to sound or infrared radiative cooling. The former is addressed in the next unit of study in the 8th grade scope and sequence: *Unit 8.2: How can a sound make something move? (Sound Unit)*. The latter is beyond grade-band targets for the disciplinary core ideas.

The energy transfer and force interaction model that you develop for the launcher system in this lesson and revise in the next lesson will include contact forces acting in the horizontal direction only. The model will not include contact forces that are the result of gravity (e.g., normal forces). Considering forces in more than one dimension at a time is also an off-grade-band learning target (high school).

1. Navigation

8 MIN

Materials: None

Share questions that were raised at the end of the last lesson.* Say, *At the end of the last class, we started considering energy transfer in the launcher, cart, track, and box system in order to better understand what is happening in that system. What new questions did thinking about energy transfer in the entire system raise for you?* Display **slide A.** Discuss these questions as a class.

Suggested prompt	Sample student responses
What new questions did thinking about energy transfer into and through the entire system raise for you?	*Do we put energy into the system?* *How does the cart get energy anyways?* *Does the tension of the spring have energy?* *Does pulling the spring back different amounts give it different amounts of energy?* *How does energy from you get to the cart?* *Does the energy go into the ground?* *Does energy go into the cracker or the brick?* *Do the opposing forces between objects cancel out some of the energy in the system?* *Is all the energy that goes into the cart going into the box?* *If energy goes into the ground, what happens to it when it goes there?* *Does the energy go other places outside of the system and we just can't detect it?*

Say, *In order to think about the energy transfer into and through an entire system, scientists and engineers often break bigger systems into subsystems to try to figure out what is going on. You've done this in many of the previous units in earlier grades. Let's recall a few of those examples to think about how powerful this type of system thinking has been for us in the past.* Ask students for examples based on the prior unit experiences.

*** Supporting Students in Developing and Using Systems and System Models**

Prior to this lesson students have been thinking about different components of the cart subsystem with a lens of the matter moving and the resulting damage due to this movement. Now students are beginning to think about how energy is part of this system. They make connections to how objects within the larger cart system interact with each other and how different components of the system and subsystems are interrelated, causing objects to move and eventually stop.

Suggested prompts	Sample student responses
What were the subsystems you used to try to explain why different people saw different things on either side of a one-way mirror in your work in Unit 6.1: Why do we sometimes see different things when looking at the same object? (One-way Mirror Unit)?	*Two different rooms, the surface of the mirror, different people at different locations.*
What subsystems did you identify for the cup in your work in Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit) to try to think about how energy was transferring through the larger system?	*The liquid, the walls and lid, the air between separate walls, and the air outside the cup.*
What subsystems did you focus on to think about energy transfer into the formation of a hailstorm in Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit)?	*The light's interaction with the ground and/or surface.* *The interaction between the Earth's surface and the air above the surface.* *Parcels of air rising and falling.*
What subsystems did you break the body into to think about what was causing M'Kenna to feel the way she did in Unit 7.3: How do things inside our bodies work together to make us feel the way we do? (Inside Our Bodies Unit)?	*The digestive system, the circulatory system, and the respiratory system.* *Cells within specific tissues or organs.*

Say, *These are great examples of where breaking the bigger systems into subsystems helped us figure out what was going on. Such system thinking is a powerful crosscutting concept that helped us make sense of more complex systems in the past. In addition to breaking up the system into smaller objects or smaller subsystems, it can also be useful to try to take what is happening in a given period of time and try to break it down into smaller chunks of time. In our launcher system, there was a lot happening between getting ready to launch the cart and seeing what the results were. So it may be useful to think about specific moments in time before, during, and after the cart is launched as well as before, during, and after the box is pushed. Throughout each period of time it may also be useful to think about the interactions occurring between different subsystems and objects within the larger system.*

2. Individual Explanations

5 MIN

Materials: science notebook, *Tracking energy transfers in our launcher system*

Develop initial explanations for where energy transfers may be occuring. Display **slide B.** Distribute *Tracking energy transfers in our launcher system*. Have students add this to their science notebooks. Give students about four minutes to answer the questions on the handout.

3. Develop a Consensus Model of energy transfers in the system. 20 MIN

Materials: science notebook, *Energy transfers and contact forces in the launcher, cart, track, and box system*, colored pencils, Energy transfers and contact forces in the launcher, cart, track, and box system poster, colored markers, 13 prelabeled sticky notes (9 triangular with words, 2 square with red dots, and 2 rectangular with blue curved arrows).

Discuss where energy transfer is occuring in the system. Display **slide C**. Convene students in a Scientists Circle to discuss some of their ideas.

Suggested prompts	Sample student responses
What did your group do to the launcher so that it could eventually transfer energy to the cart?	*We used our hands to pull it back.* *We pushed into the plunger or against the cart to push it backward.* *We compressed the spring in the launcher.*
What did your group do differently to the launcher so that it could transfer more energy to the cart for condition B or C compared to condition A?	*We pulled it back further.* *We pushed it back harder or further.*
What part of the launcher subsystem directly transferred energy to the cart to get it moving?	*The tip of the plunger.*
How did that part of the launcher subsystem transfer energy to the cart?	*It pushed on the cart as it returned to its original position.* *Contact forces between the plunger and the cart.*
What did the launcher do after you released it that enabled it to transfer more energy to the cart in condition B or C than in condition A?	*It pushed with a stronger force at first when it was released from a more-compressed position.* *It pushed the cart over a longer distance (or time).*

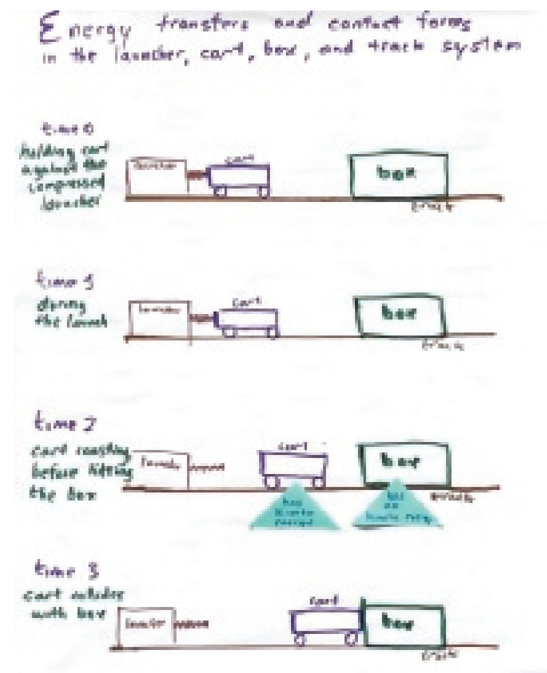
Switch to a diagrammatic representation of the system. Say, *Let's capture all of these ideas in a system diagram of the spring launcher, cart, track, and box system. We can use this model to show how energy was transferred through the spring-scale-launched cart system that collided with the box.*

Distribute *Energy transfers and contact forces in the launcher, cart, track, and box system*. Ask students to compare the objects or subsystems represented for each of the times shown in the model and describe what is different and what is the same for each time shown.

Suggested prompt	Sample student response
What objects or subsystems are represented in this system model?	*The launcher, the cart, the box, and the track,.*

Suggested prompts	Sample student responses
What is different about these objects in some of the times?	*The launcher spring is compressed in time 0, but not the other times.* *The cart is moving in times 1 through 4, but not in time 0 or time 5.* *The position of the box is the same in times 0 through 2, but changes in times 3 through 5.*
What does time 0 show?	*The cart before it is launched.*
What does time 2 show?	*The cart traveling down the track after it is launched.*
What does time 5 show?	*The box and cart after they came to a stop.*

Post the premade poster that you created representing the Energy transfer and contact forces in the launcher, cart, box, and track system model. You will use the 18 prelabeled sticky notes (14 triangular, 2 square, and 2 rectangular) to annotate this model so that you can remove these annotations before the next class and repeat this interaction-system-modeling exercise and discussion with your next class.



Direct students' attention to time 2 and time 0. Ask students which objects or subsystems have kinetic energy and which do not at time 0 and time 2. Students should say only the cart in time 2 has kinetic energy and nothing else does.

Add the triangular sticky note "has kinetic energy" to the cart at time 2.

Add the triangular sticky note labeled "has no kinetic energy" to the cart at time 0 and the box at both time 0 and time 2.

Have students add the same annotations to their copy of *Energy transfers and contact forces in the launcher, cart, track, and box system*.

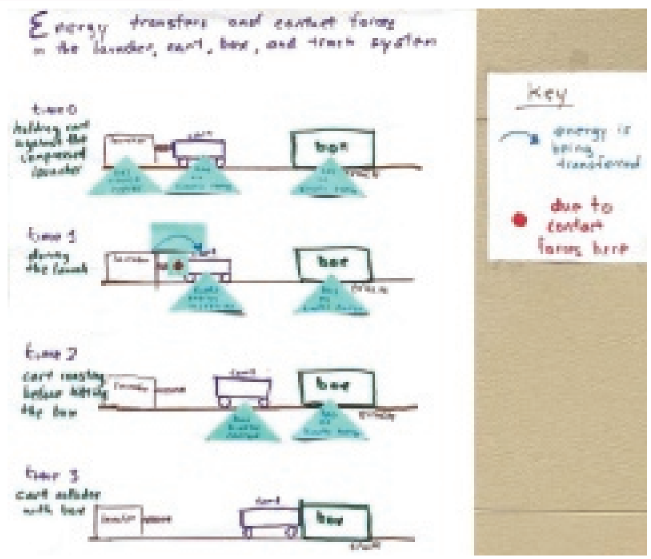
Introduce the idea that energy can be stored in systems in some cases when the shape or position of parts or objects changes. Say, *When we compressed the spring scale and held the cart motionless against it, it wasn't moving, so therefore it has no kinetic energy. But we know energy is transferred from the launcher to the cart when we release it. The compressed spring scale is an example of a subsystem that can store energy that can be transferred out of it later. Compressing the spring by pushing on it allowed us to transfer energy into that part of the subsystem. Holding the spring in place allowed it to remain in a particular shape or position where it could continue to store that energy. And letting go of it allowed the launcher to spring back to its original shape or position. As it returned to its original shape or position, the energy that was stored in that part of the subsystem was transferred back out of it. Scientists also refer to the stored energy in a system that is the result of a change in the position of objects in the system as* potential energy.

Additional Guidance

Referring to this energy stored in the configuration of the parts of a system as "potential energy" has some trade-offs in terms of simplicity of understanding versus accuracy of representation. But it will be beneficial for future work—thinking about energy stored in magnetic fields due to the position of the magnets relative to each other—in *Unit 8.3: How can a magnet move another object without touching it? (Magnets Unit).* The spring launcher will be an analogous physical structure that students use to visualize what is happening when a magnetic field is deformed. Springs are a more-concrete way to visualize how energy can be stored in a system before introducing the idea that energy is stored in the field of a system due to distance forces. So more exactly, it's not the spring that is storing the potential energy, it is the spring system. In that system it ultimately is the electric field between the atoms that make up the spring launcher and the matter that it is in contact with that holds the spring in a compressed form. In that form, the position and orientation of the atoms that make up the matter shift and the field between them stores the energy in the system. This is beyond grade-level understanding and would not be beneficial to introduce here.

Review what is causing the energy to get transferred into and out of the system.

Suggested prompts	Sample student responses
What did we do to the push-pull spring scale system that provided it energy that it could later transfer to the cart?	*We compressed it.*
What happens to the amount of stored or potential energy in the spring-launcher system as we compress the spring more?	*It increases.*
How did letting go of the cart cause the potential energy in one part of the system to get transferred out of it into the cart as kinetic energy?	*The kinetic energy from the push of the spring scale as it uncompressed transferred from the spring to the cart.* *From contact forces between the spring scale and the cart.*



Add the triangular sticky note labeled "has stored energy" to the launcher at time 0.

Make a key on a piece of letter sized paper taped to the side of the poster. Add a curved blue arrow to the key and label it "energy is being transferred".

Add a rectangular sticky note with a curved, blue arrow going from the launcher to the cart at time 1.

Add a red dot to the key and label it "due to contact forces here". Then ask students where the contact forces are between the launcher and the cart at time 1 that are causing this energy transfer. Students should say where the plunger is touching the back of the cart. Add a small square sticky note with a red dot on it to that location at time 1.

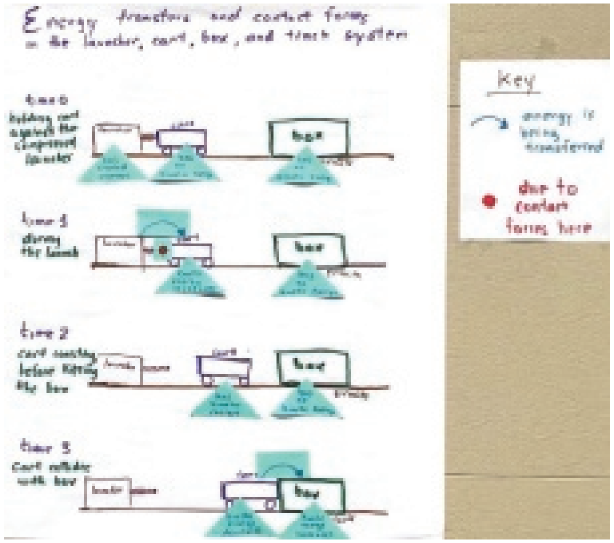
Add the triangular sticky note labeled "kinetic energy increases" to the cart at time 1.

Have students add the same annotations to their copy of *Energy transfers and contact forces in the launcher, cart, track, and box system.*

Point out that the red dot shows where the contact forces are occurring in the system but doesn't show how many forces there are at that point of contact nor their relative strength like we showed earlier when we made a free body diagram of each object or subsystem in a collision.

For time 1, review how many forces there are at this point of contact and their relative strength.

Suggested prompts	Sample student responses
If we did make individual free body diagrams to represent the contact forces at work in the system, would we show that there is a single force acting on the launcher, a single force acting on the cart, or a force acting on both?	*A force acting on both.*
How would the relative strength of the forces on both compare? Would they be different strengths or would they be the same strength?	*They would be the same strength.*
How would the direction of the forces on both compare?	*They would be in opposite directions.*



Prompt students to consider time 3. Ask students what happens to the stationary box when the cart collides with it. Students should say it starts moving.

Ask students where the energy was transferred from that causes the kinetic energy of the box to increase. Students will say from the cart.

Add the triangular sticky note labeled “kinetic energy increases” to the box at time 3.

Add a rectangular sticky note with a curved, blue arrow going from the cart to the box at time 3.

Then ask students what must be happening to the kinetic energy of the cart if energy is being transferring from it to the box during the collision. Students will say it must be decreasing.

Add the triangular sticky note labeled “kinetic energy decreases” on it to the cart at time 3.

Ask students to identify where the contact forces are between the cart and box. Add a small square sticky note with a red dot on it to that location.

Emphasize that, again, we have identified a location in the system where energy transfer is occurring due to contact forces between two objects or subsystems. Have students add the same annotations to their copy of *Energy transfers and contact forces in the launcher, cart, track, and box system*.

Direct students to time 5, suggesting that you want to identify a few things here first before returning to time 4.

Ask students what we can say about the kinetic energy of all the objects or subsystems at time 5 if everything has stopped moving. Students will say that they have no kinetic energy. Have students add these annotations to the cart and the box in time 5 on their copy of *Energy transfers and contact forces in the launcher, cart, track, and box system*.

Direct students to time 4, asking what is happening with the speed of the cart and the box as they slide along the track to a stop. Students will say they are slowing down. Have students label both the cart and the box with “KE decreases”.

Problematize something missing from the model. Say, *Wait, where did the energy in the system go between time 3 and time 5. Some of the objects had kinetic energy at time 3, but by time 5 there is no kinetic energy in the system. Energy can’t just disappear. It can be transferred from one object, subsystem, or system to another. We saw that happen due to contact forces between certain objects and subsystems at time 1 and time 3. But here at time 4 it’s not obvious where that energy* *went, nor is it obvious what contact forces would have caused this energy transfer. So I don't think we are done with this model yet. But let's have you think on your own a bit more about what else might be going on in this system from both an energy transfer perspective and a contact forces perspective.*

4. Individual Models

7 MIN

Materials: science notebook, *Energy transfers and contact forces in the launcher, cart, track, and box system*, *Modeling other force interactions in the launcher, cart, box, and track system*, colored pencils, Contact Force Interactions poster from Lesson 5 (optional)

Say, *We put red circles in our systems model to show where contact forces are occurring. In the past, when we wanted to show more about what the forces are at those red circles, we drew free body diagrams. We haven't done that for any of our points in time in the model so far. But let's not forget that free body diagrams are a helpful tool for visualizing the forces acting on objects in the system. Let's get ready to develop and revise some free body diagrams for both the box and the cart at time 4. Before we do, let's look back at how we drew the free body diagrams we made in the past.*

Review what was included in past free body diagrams the class made in Lesson 5. Cue students to look back at an example of the ones they made in their notebooks and/or on the poster you made as class from Lesson 5.

Suggested prompts	Sample student responses
Even though there are two objects interacting when there are contact forces between them, how many objects do we show in a single free body diagram?	*One.*
What do the arrows in the diagram represent?	*A force acting on the object.*
What does the direction of the arrow represent?	*The direction of the force on the object.*
What are we trying to show when we put the tip of the force arrow on one surface of the object instead of another?	*Which surface that force is acting on.*
Up to now you have only shown a single force acting on an object. Next you will be asked to consider if there are other forces acting on those objects as well. If you decide there are, then how would you show more than one force acting on an object?	*Use more than one arrow.*

Show **slide D**. Distribute *Modeling other force interactions in the launcher, cart, box, and track system*. Say, *Use the annotations we made to Energy transfers and contact forces in the launcher, cart, track, and box system and consider what else might be going on at time 4, starting first by thinking about forces in the system using free body diagrams.* Emphasize that you want to collect this as a formative assessment to see how students are thinking about other forces acting on the box and the cart at this point in time as well as how and where energy transfer may be occuring.

Collect the completed responses before moving to the end of the lesson.

Assessment Opportunity

Building towards: 8.A Develop and use a model to identify other parts of the system the cart and box are making contact with or colliding into that could be producing contact forces on these subsystems, causing energy to be transferred to or from them as the box and cart travel down the track.

What to look for: See *Key for modeling force interactions in the launcher, cart, box, and track system* for guidance on what to look for.

What to do: Treat this as an informal assessment of prior knowledge related to how forces from friction and air resistance act on moving objects. Do not correct preconceptions at this point. Make a copy of student responses on *Modeling other force interactions in the launcher, cart, box, and track system* so you can return the original to students to revise at the end of the next lesson (Lesson 9) as a home-learning assignment. This will provide you a reference to compare student thinking before Lesson 9 to what they are thinking by the end of Lesson 9.

5. Navigation

5 MIN

Materials: 4 index cards, 1 rubber band, *Investigating Surface Interactions*, *Investigating Interactions with the Air*, Energy transfers and contact forces in the launcher, cart, track, and box system poster, 18 prelabeled sticky notes (14 triangular, 2 square, and 2 rectangular).

Discuss other sources of contact forces as a whole class.

Suggested prompts	Sample student responses
What other objects or subsystems is the box either making contact with or colliding with at time 4 besides the cart?	*The track.*
The track is something that is easy to see the box making contact with. But the cart also makes contact with it or the surface under it. Are there any other sources of matter that the box and cart are colliding with or making contact with besides the track and surface under it?	*The air.*
If we were to zoom in and try to visualize what is happening to the particles that make up the air, what do you picture happening to those particles when the box and cart run into them?	*They would get pushed out of the way.* *They would hit the box or cart and bounce off.*
What part of the box would be hitting the most air particles as it is sliding down the track?	*The front.*
What part of the box is making contact with the track as it is sliding down it?	*The bottom.*

*** Attending to Equity**
Universal Design for Learning: You may find that some students want to *engage* with these investigations and ask to do both at home. If so, encourage them to do so, but don't require this of all students. Providing an option of which investigation to do rather than requiring both gives students a choice to pursue a line of inquiry that is more relevant to them. Some may consider both intriguing, and for those students, giving them the choice to pursue both is also an important option to *engage* students as well.

Introduce the ideas of friction and air resistance. Students may or may not have used the words *friction* and *air resistance* at this point in the unit. If students have used these terms, acknowledge the terms here. If they have not, start to link the words with the concepts. Use one of the two prompts below that best fits your classroom case.

- Option 1: Introduce what these two sources of contact forces are commonly called. Say, *The contact forces between a moving object and something it is sliding against are commonly called* friction*, and the contact forces between a moving object and the air particles it collides with are commonly called* air resistance.
- Option 2: Acknowledge the use of the words *friction* and *air resistance*. Say, *I hear you all saying the word* friction *to describe the forces between an object and something it is sliding against. I also hear you using the word* air resistance *to describe contact forces between a moving object and the air particles that it collides with. These are interesting words. Let's see if we can really develop our ideas of what these terms mean as we explore these contact forces.*

Ask students for a few examples in other systems or phenomena where they think that contact forces due to friction affect the kinetic energy of an object as it moves. Do the same for air resistance. Accept all responses.

Additional Guidance

Don't add the terms *friction* or *air resistance* to the Word Wall yet. You will do that at the start of the next lesson after all students have gathered some first-hand experiences with related phenomena in the home learning.

Suggest that since these forces may be part of many other systems where there are objects moving, what causes these forces and how they affect the motion of objects before, during, and after a collision appears to be another part of the system model we will need to figure out more about in order to answer our unit driving question, "Why do things sometimes get damaged when they hit each other?".

Introduce home learning. Show **slide E**. Say, *Tonight you have an option to do one of two investigations. One of these involves folding and dropping index cards to see which shapes you can get to travel more quickly and more slowly through the air. The other involves pulling on a shoe with a rubber band to see how much force it takes to get it to start moving when it is on different surfaces. I will give you supplies that can be used for either investigation, which are four index cards and a rubber band. You pick which investigation you want to do. If you do the latter investigation you will also need a shoe and a ruler.*

Distribute four index cards with a rubber band wrapped around them to each student.

Distribute *Investigating Interactions with the Air* to students who select the first investigation to carry out. Distribute *Investigating Surface Interactions* to students who select the second investigation to carry out.

Tell students that they will share their results with other students at the start of the next class.

Remove the 18 prelabeled sticky notes (14 triangular, 2 square, and 2 rectangular) from the poster and set them to the side before the next class so they can be reused for placement on the poster.

LESSON 9

How do other contact forces from interactions with the air and the track cause energy transfers in the launcher system?

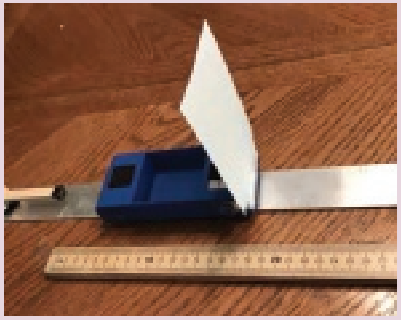
Previous Lesson

We developed a model to show where energy is transferred between the spring, cart, and box and how contact forces cause this energy transfer. We used this to start brainstorming other places where contact forces may be causing energy transfer in the system.

This Lesson

Investigation

2 DAYS



We conduct investigations to gather evidence to explain what other forces affect the kinetic energy of an object before a collision. We develop claims using our evidence and provide and receive feedback with peers to synthesize our ideas. We revise our model to show additional places in the launcher system where energy is transferred and how contact forces cause this energy transfer.

Next Lesson

We will revisit the Lesson 1 collision types and explain why some objects were damaged when others were not in different collisions. We will use these ideas to answer questions on the Driving Question Board and take an assessment to apply our new ideas to a new set of collision-related phenomena in the context of baseball.

Building Toward NGSS

MS-PS2-1, MS-PS2-2, MS-PS3-1, MS-ETS1-2, MS-ETS1-3, MS-LS1-8

What Students Will Do

9.A Apply scientific ideas and evidence to construct an explanation for the causes of motion and kinetic energy changes that happen before and after collisions and how these affect the outcome of a collision.

9.B Respectfully provide and receive critiques about claims to identify relevant evidence to support an explanation for how energy transfers through the cart-launcher system before and right after a collision.

9.C Develop and revise a model to identify other parts of the system the cart and box are making contact with or colliding into that are producing contact forces on these subsystems, causing energy to be transferred to or from them as the box and cart travel down the track.

What Students Will Figure Out

- Friction is a contact force due to interaction between surfaces in contact and is produced by the bumps (roughness) on surfaces as they push against each other.
- Interactions due to friction and air resistance apply contact forces to a moving object that are in a direction that is opposite its motion.
- Force interactions due to friction and air resistance transfer energy to the surfaces of the objects that slide over each other; this results in an increase in particle-level kinetic energy (a temperature increase).
- Energy can be transferred to and from collisions between objects and particles in the air.

Lesson 9 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	**SHARING RESULTS FROM OUR HOME LEARNING INVESTIGATION** Discuss observations from home learning investigations assigned at the end of Lesson 8.	A	*Investigating Surface Interactions*, *Investigating Interactions with the Air*, optional: 1 shoe, optional: 1 rubber band, optional: 1 carpet square, optional: 4 index cards
2	5 min	**NAVIGATION** Recollect ideas about how speed and mass both affect the kinetic energy of an object.	B	*Investigating Surface Interactions*, *Investigating Interactions with the Air*
3	25 min	**CONDUCTING INVESTIGATIONS: OTHER FORCES IN OUR COLLISION SYSTEM** Conduct station investigations to explore other forces in a collision system.	C	Other Forces in Our Collision System Investigation
4	10 min	**CONSTRUCT AN EVIDENCE-BASED EXPLANATION** Construct explanations for investigations done at the stations.	D	blank sheet of paper (optional)
				End of day 1
5	5 min	**NAVIGATION** Connect to previous explanations of each investigation station.	E	
6	22 min	**JIGSAW FEEDBACK GROUP DISCUSSION** Present and defend explanations for the cause-effect relationships for the motion and kinetic energy changes in the launcher system.	F-G	*Jigsaw feedback discussion*

Part	Duration	Summary	Slide	Materials
7	14 min	**REVISE OUR MODEL** Gather in the Scientists Circle to revise our collision system model and describe motion and KE changes that result from friction and collisions with air particles.	H-I	*Energy transfers and contact forces in the launcher, cart, track, and box system*, colored pencils, Energy transfers and contact forces in the launcher, Lesson 8 cart/box/track system poster
8	4 min	**NAVIGATION** Introduce home learning.	J	*Modeling other force interactions in the launcher, cart, box, and track system*, colored pencils, *Key for modeling force interactions in the launcher, cart, box, and track system* *End of day 2*
		SCIENCE LITERACY ROUTINE Upon completion of Lesson 9, students are ready to read Student Reader Collection 3 and then respond to the writing exercise.		Student Reader Collection 3: Kinetic Energy and Objects in Contact

Lesson 9 • Materials List

	per student	per group	per class
Other Forces in Our Collision System Investigation materials	• *Data collection from stations*	• 1 aluminum bar track (3 ft x 1.5 in x ⅛ in) • 2 carts • 1 index card taped to cart • painters tape • 1 timer • 1 fan • 1 meter stick • *Station 2 data cards* • 1 large rubber eraser • 1 Styrofoam takeout container • 1 infrared thermometer • *Microscopic image cards* • Computer • friction simulation (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)	• 2 copies of *Lab station instructions*

	per student	per group	per class
Lesson materials **Student Procedure Guide** **Student Work Pages**	• *Investigating Surface Interactions* • *Investigating Interactions with the Air* • science notebook • blank sheet of paper (optional) • *Jigsaw feedback discussion* • *Energy transfers and contact forces in the launcher, cart, track, and box system* • colored pencils • *Modeling other force interactions in the launcher, cart, box, and track system*		• optional: 1 shoe • optional: 1 rubber band • optional: 1 carpet square • optional: 4 index cards • Energy transfers and contact forces in the launcher Lesson 8 cart/box/track system poster • *Key for modeling force interactions in the launcher, cart, box, and track system*

Materials preparation (60 minutes)

Online Resources

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Modify **slide F** to replace it with the classroom norms your classes developed, if they are different than those shown on the slide.

Be prepared to distribute the completed copies of *Modeling other force interactions in the launcher, cart, box, and track system* you collected and copied from last time.

Have the Energy transfers and contact forces in the launcher, cart, box, and track system poster from the last lesson along with corresponding sticky note annotations added to it from the last lesson.

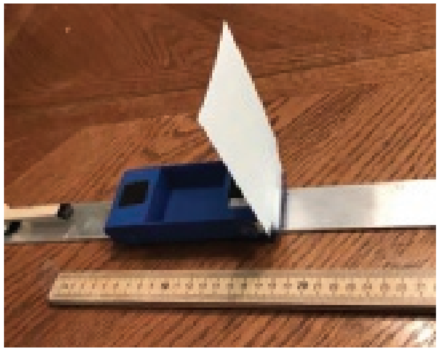
Test the simulation link to make sure it is working. (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

Day 1: ***Other Forces in Our Collision System Investigation***

- **Group size:** 3–4 students
- **Setup:** Gather materials for 8 stations, 2 each of the following 4 stations:
  - **Materials for station 1**
    - 1 aluminum bar track (3 ft x 1.5 in x ⅛ in)
    - 2 carts
    - 1 index card attached with transparent tape to 1 cart
    - 1 small fan
    - 4 6-inch pieces of painters tape to secure track
    - 1 timer
    - 1 meter stick

- **Materials for station 2**
    - *Station 2 data cards*
- **Materials for station 3**
    - 1 large rubber eraser
    - 1 Styrofoam takeout food container broken into 2 pieces
    - 1 infrared thermometer
- **Materials for station 4**
    - *Microscopic image cards*
    - 1 computer or tablet with access to the friction simulation (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)
- **Make single-sided copies of station handouts:**
    - 2 copies of *Lab station instructions*
    - 2 copies of *Station 2 data cards*
    - 2 copies of *Microscopic image cards*

- **Safety:**
    - Wear safety goggles or glasses during the setup, hands-on, and take-down segments of the activity.
    - Never eat any food items used in a lab activity.
    - Make sure all other fragile items are removed from the test area.
    - Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
    - Immediately pick up any items dropped on the floor so they do not become a slip/fall hazard.
    - Follow your teacher's instructions for disposing of waste materials. Wash your hands with soap and water immediately after completing this activity.
- **Storage**
    - All materials from this lab can be stored and reused indefinitely.



Lesson 9 • Where We Are Going and NOT Going

Where We Are Going

In this lesson, students account for forces due to friction and air resistance that are not yet accounted for in the collision system model. This serves three purposes:

- Investigating kinetic energy and motion changes that result from friction and air resistance forces sets the stage for revising the class collision system model and tracking the flow of energy more completely through the system.
- Students will have a better understanding of how multiple forces affect the motion and kinetic energy of an object and will use this to build an explanation for net force in Lesson 10.
- Students also consider how friction and air resistance forces can cause a collision to be less severe, which foregrounds the design challenge in Lesson Set 3.

These ideas are part of the DCI PS2.A and contribute to meeting MS-PS2-2 with regard to exploration of unbalanced forces: "Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object."

Where We Are NOT Going

Students will account for forces due to friction and air resistance in the class collision system model, but there will be some points of contact in the model that are not yet explained. This wondering at the end of class sets the stage for a better understanding of how objects behave when they experience multiple forces and the concept of net force in future lessons.

LEARNING PLAN FOR LESSON 9

1. Sharing Results from Our Home Learning Investigation

5 MIN

Materials: *Investigating Surface Interactions*, *Investigating Interactions with the Air*, optional: 1 shoe, optional: 1 rubber band, optional: 1 carpet square, optional: 4 index cards

Revisit home learning. Say, *After our last lesson, you completed some investigations at home, so let's share our results with a partner.* Display **slide A**. Have students stand up and move to one of 3 different areas of the room that corresponds to the investigation(s) they completed:

A. Interactions with the Air investigation

B. Surface Interactions investigation

C. both investigations

Instruct students from area A to pair up with someone from area B. Any extras in either group should pair up with someone from area C. Any extras in area C after that can pair up with each other.

*** Attending to Equity**

Emerging Multilingual Learners: It may be helpful to intentionally pair emerging multilingual students with peers whose English language development is similar to theirs to explain their home learning results. Encourage students to express their ideas using linguistic and nonlinguistic modes such as drawings, symbols, and gestures. If possible provide hands-on materials (e.g., shoe, rubber band, carpet square, index cards) for students to demonstrate their ideas.

2. Navigation

5 MIN

Materials: *Investigating Surface Interactions*, *Investigating Interactions with the Air*

Lead a whole-group discussion using the question on the slide. Say, *We know from our last lesson that speed and mass both affect the kinetic energy of an object. We also know that something is causing objects (like the cart and box) to lose kinetic energy after a collision.* Display **slide B**. Use the prompts below to support this brief discussion.

Suggested prompts	Sample student responses
What ideas do you have from the home learning that could help explain other contact forces in the system that may be causing the box to slow down and eventually stop?	*There is a contact force between the bottom of the box and the surface it is sliding over.* *There also is a contact force from running into air particles as the box slides down the track.*
So what other places in the system would the energy that the box had get transferred to then?	*To the air.* *To the track.*
What do we know about air from earlier units, like Cup Design Unit, that could be causing things that interact with the air to slow down?	*Air is made of small particles that can collide with objects.*
Do you think that contact forces between the cart and the air also cause the cart to slow down as it travels down the track?	*The air would. The cart would still be colliding with air particles.*
Do you think that contact forces due to friction between the cart and the track also cause the cart to slow down as it travels down the track?	*Maybe. But there is probably less friction than for the sliding box.*

Connect this to energy transfer questions from the last lesson. Say, *In our last lesson we raised some new questions about where energy was going to in the system. Let's decide what we should do next.*

Motivate the need for further investigations. Say, *OK, it sounds like we are going to need to update this system model. And it sounds like we should collect some more evidence about some of the places where these contact forces are causing energy to be transferred to other parts of the system. I have some equipment and materials we can use to investigate these types of interactions further. Let's make note of the question we are trying to make further progress on.*

Write this question on the board:

- How do other contact forces, like friction and air resistance, cause energy to be transferred between a moving object and other parts of a system?

3. Conducting Investigations: Other Forces in Our Collision System

25 MIN

Materials: Other Forces in Our Collision System Investigation

Share directions for station investigations. Display **slide C**. Explain that student groups will rotate through four stations where they will investigate other instances of objects slowing down or producing another interesting outcome related to one of the two additional types of contact forces we have discussed are missing from our system model—friction and air resistance.

*** Supporting Students in Engaging in Planning and Carrying Out Investigations**
The current collision system model is only partially complete in terms of energy transfers. As

Be sure to post the activity instructions, *Lab station instructions*, at each station. Distribute *Data collection from stations* and tell students to record on the handout their observations and any insights they have about these other forces that are not accounted for in our model.*

Allow students approximately 20 minutes to engage in the stations, asking them to rotate every 5–6 minutes.

4. Construct an evidence-based explanation. 10 MIN

Materials: science notebook, blank sheet of paper (optional)

Construct an evidence-based explanation. Display **slide D**. Say, *Next time, we will work as a class to identify the most relevant ideas we have for developing a more-complete model of the forces affecting moving objects before, during, and after a collision. Today, let's spend the last few minutes of class organizing the ideas you have now into some explanations.*

Have students count off 1-4 to assign each student **one** of the stations from today's investigations. Explain that each student will create an explanation for the one station they have been assigned, not all stations they visited. This will allow for multiple individuals to analyze the same data, and as a class we can compare findings later, which is what scientists also do in their professions. Say, *When you develop your explanation you will focus on the evidence collected and the observations and insights you recorded from only one station. Your explanation should help answer the question:* ***How do other contact forces, like friction and air resistance, cause energy to be transferred between a moving object and other parts of a system?*** *Be sure to describe what causes these forces, how these forces transfer energy in the system, and the evidence from your assigned station investigation that supports your explanation.* ** *I will collect your explanations so I can get a sense of what you are thinking and then return them to you next time.*

Give students time to write and collect their work at the end of class. Students can write explanations in their notebooks or on blank paper for ease of collection.

Assessment Opportunity

Building towards: 9.A Apply scientific ideas and evidence to construct an explanation for the causes of motion and kinetic energy changes that happen before and after collisions and how these affect the outcome of a collision.

What to look/listen for: As you formatively assess student explanations look for these ideas: For friction-related explanations

- When surfaces in contact with each other slide along each other, the bumps (roughness) on their surfaces cause an interaction (effect).
- That interaction (cause) results in the surface deforming (effect).
- That deformation (cause) results in that part of the matter pushing back on the object it is in contact with (effect).
- This force applied against the moving object is friction. It causes the cart or box to slow down (effect).
- These contact forces (cause) cause energy to be transferred to the surfaces in contact with each other, resulting in an increase in the particle-level kinetic energy (an effect measurable by a temperature increase).

students are conducting station activities, their focus should be on gathering evidence to explain additional effects from friction and air resistance that cause changes in motion and KE of subsystems within the collision system. An important goal of the observations and data collected under different conditions at stations is to push students to think about evidence of changes in motion and KE in terms of particle motion.

*** Supporting Students in Three-Dimensional Learning**

Scientific explanations often center around events that have unobservable causes and that generate observable effects. Each of the stations provides students with opportunities to look for changes in the macroscopic motion of an object (patterns) and the relationship to the microscopic particle nature of matter to explain what causes force pairs from friction and air resistance in general, as well as where this is occurring in the class's cart-launcher system in a specific case.

*** Attending to Equity**

Universal Design for Learning: If students struggle to get started, you can provide the sentence frames for cause-effect statements used in Lesson 2, such as these:

- When the cart traveled along a track with a sail/without a

For air resistance-related explanations

- When an object moves through air (cause), it collides with air particles (effect).
- These collisions cause contact forces (effect) on both the object and the air particles.
- The force applied against the moving object is air resistance. It causes the cart or box to slow down (effect).
- These contact forces (cause) cause energy to be transferred to the surrounding air, moving it out of the way of the cart (or speeding up those particles).
- In the interaction with the cart being pushed by a headwind, the wind is a resistant force and KE is expended on the wind.
- In the interaction with the cart being pushed by a tailwind, the wind is not a resistant force but adds KE to the overall cart system.
- There often is more than one contact force on a moving object (such as surface friction, air resistance, and wind).

Assessment Opportunity

What to do: You can scaffold the activity to support students in identifying appropriate data and justifying their explanations with reasoning by providing sentence frames. This will help them organize data and observations and reference the science ideas they've figured out so far.

Referencing data

- When we did the ____ (description)______ investigation, the data showed that ___________.
- We saw _(description of the data)_ from our investigation.

Using science ideas

- This means that __________ caused _________ (effect) because we know _(science idea)_.

End of day 1

5. Navigation

5 MIN

Materials: science notebook

Connect to explanations for investigation stations from the previous class. Return student claims. Display **slide E**. Say, *Today we are going to work in jigsaw feedback groups to share our claims. Each group will consist of students who wrote claims about different stations. Each station will have at least one person in the group who wrote a claim about it. Before we begin, take some time to think about how you will share your claim and highlight or underline the important ideas you want to emphasize with your classmates.*

sail, _(cause)__, which results in a __(effect)_.

- When a boat or cyclist travels into a headwind/in the same direction as a tailwind, _(cause)__, which results in a __(effect)_.
- When two surfaces slide past each other, _(cause)__, which results in a __(effect)_.

*** Supporting Students in Engaging in Argument from Evidence**

Emphasize to students that claims should be written so as to answer the lesson question. Encourage them to think carefully about organizing their evidence and reasoning so that their explanation is persuasive. This is important because in the next class meeting they will shift to sharing this as an argument they make to their peers in mixed groups so that all stations are represented.

*** Supporting Students in Developing and Using Patterns**

In student explanations, it's important for them to connect the macroscopic changes in motion and kinetic energy they observe to the microscopic arrangement of particles of objects and subsystems. Students should draw on what they already know about how matter pushes back and that forces occur in equal and opposite pairs. The particle-level thinking in this lesson supports developing a deeper understanding of *why* matter pushes back.

6. Jigsaw Feedback Group Discussion

22 MIN

Materials: science notebook, *Jigsaw feedback discussion*

Discuss norms for giving and receiving feedback.* Display **slide F**. Ask students to revisit the classroom norms and to share ideas for which norms are especially important when giving and receiving feedback. Allow a few students to quickly share their thinking with the class and listen for ideas such as the following:

- We critique ideas, not people.
- We encourage other voices that haven't been heard yet.
- We listen carefully and ask questions to help us understand.

Say, *These are all important to help us learn from each other as we share our explanations in our groups.*

Display **slide G**. Explain that group members will each take turns sharing and defending their explanations. Distribute *Jigsaw feedback discussion*. Guide students to use the discussion questions on this handout to push thinking about each of the four stations so that students can explain the cause-effect relationships for the motion and kinetic energy changes in the launcher system.*

Say, *Spend five minutes discussing the explanation made for each station. As you engage in discussion with your group, listen for similarities and differences in your claims and identify the most relevant ideas to add to our model and add those to your handout.*

Determine a way to keep time and let students know each time 5 minutes has passed.

Additional Guidance

Student jigsaw feedback groups should consist of 4 students so that there are 4 different claims to discuss in alignment with the 4 stations investigated in the previous class meeting. To save time, make and post these group assignments in advance. Make as many groups of 4 that represent all 4 stations as possible, and if there are groups missing any station claims, ask them to discuss all questions on *Jigsaw feedback discussion* even though they may not have a claim for a particular station.

Assessment Opportunity

Building towards: 9.B Respectfully provide and receive critiques about claims to identify relevant evidence to support an explanation for how energy transfers through the cart-launcher system before and right after a collision.

What to look for: Students should be citing evidence and providing scientific reasoning to support their explanations. Group members ask clarifying questions to elicit details that reveal similarities and differences in their claims and to make connections between patterns in macroscopic observations and the particle nature of matter. Some parts of the student discussion should be focussed on *why* friction and air resistance affect the motion and kinetic energy of objects in the class collision system model as well as how the interactions that produce these forces would also affect the motion of particles in the air and on the surface of the track, box, and wheels of the cart.

*** Supporting Students in Engaging in Argument from Evidence**

Sharing ideas clearly and persuasively is an important aspect of scientific communication. As students are engaged in jigsaw group discussions, circulate and encourage students to cite evidence to support their explanations. Group members should clarify thinking and surface similarities and differences in their explanations. In order for students to make connections across the different lines of evidence from their investigations, encourage students to share and defend their claims with supports such as these talking stems:

- My idea is similar to ____'s idea.
- I agree with ____ that ____.
- I hadn't thought of that.
- I see what you mean.
- I disagree with ____'s idea because . . .
- I heard ____ say ____, but I think ____.

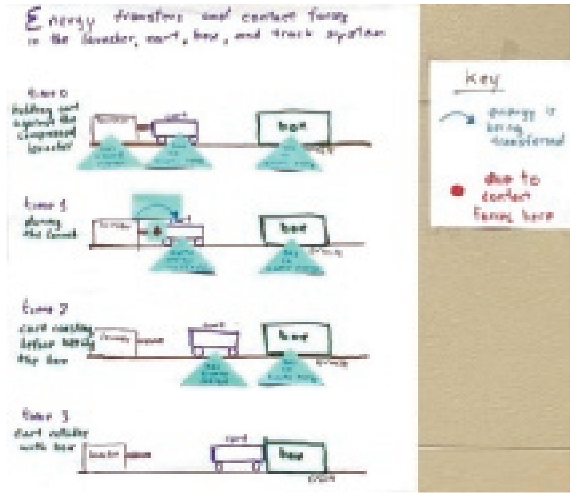
*** Supporting Students in Developing and Using Cause and Effect**

Students should relate the forces due to air resistance and friction (cause) to changes in motion of the box and cart and decrease in

What to do: If some groups aren't making some of these connections, ask those groups to focus their discussions on a subset of the questions on *Jigsaw feedback discussion*.

7. Revise our model.

14 MIN



Materials: science notebook, *Energy transfers and contact forces in the launcher, cart, track, and box system*, colored pencils, Energy transfers and contact forces in the launcher, Lesson 8 cart/box/track system poster

Gather the class in the Scientists Circle. Display **slide H**. Say, *I heard some really great connections being made as groups discussed their explanations. Let's share and record the relevant ideas we have for revising our previous model we developed for our launcher system.* Have students bring their notebooks, colored pencils, and their copies of *Energy transfers and contact forces in the launcher, cart, track, and box system*.

Display the Energy transfers and contact forces in the launcher, cart, box, and track system poster with the sticky note annotations on it, as shown here. Lead a Building Understandings Discussion to explain what other forces affect the motion and kinetic energy of the cart before a collision.**

Ask, *Does anyone have an idea to share about where else contact forces cause energy to be transferred between different parts of the launcher system?* Listen for these ideas:

- The cart is colliding with air particles, and this causes the cart to slow down and lose kinetic energy.
- The cart is slowing down and losing kinetic energy because of friction between the cart's wheels and the track.
- The track must gain kinetic energy as increased particle motion (heat) as the cart moves over the track surface.

Ask, *If there are collisions between the cart and air particles, what changes about the air particles?* Listen for these ideas:

- The air particles gain kinetic energy after collisions with the cart.
- The air particles heat up after collisions with the cart.

Suggested prompts	Sample student responses
So it sounds like we need to account for these ideas on our model. I heard you say that the cart is colliding with air particles. Where on our model is that happening?	*After the cart has been launched when it is traveling toward the box.*
What is happening to the air particles when they collide with the cart?	*They heat up and gain kinetic energy.*

the kinetic energy of both (effect) subsystems in the cart-launcher system model. Although each station provided different data, students should see similarities in their explanations related to how both friction and air resistance can cause changes to motion and kinetic energy before and after a collision. Some students may also argue that these forces are at work during the collision too.

*** Supporting Students in Engaging in Constructing Explaining and Designing Solutions**

Students have new evidence and reasoning to revise the class collision system model. Specifically, they can indicate areas where forces are occurring due to friction and air resistance. They can also more completely explain energy changes in the model and better explain why the box stops moving after the collision. There is some important foregrounding of ideas for the design challenge in Lesson Set 3 when students discuss how changes in motion and kinetic energy can lessen the severity of a collision.

*** Supporting Students in Developing and Using Energy and Matter**

This modeling activity is helping deepen the understanding that energy is not created or destroyed

Suggested prompts	Sample student responses
Besides the cart, what else is colliding with air particles as it moves?	*The box.*
What surface of the box is running into the most air particles?	*The front.*
Can someone suggest a way for us to represent this in our model?	*We could add a red circle on the front of the box at time 4 to show this is where most of the force interaction between the box and the air is occurring. We could add a red circle on the front of the cart at time 2 (and possibly time 1) to show this is where most of the force interaction between the cart and the air is occurring. And we could add blue arrows to show that this is where energy transfer to the air is occurring.*
You also said there were motion and energy changes due to friction. Where are all the places this would be happening in our model? When would this be happening?	*After the cart has been launched when it is moving along the track the friction is between the cart's wheels and the track.*
Can someone suggest a way for us to represent this in our model?	*We could add a red circle on the bottom of the box at time 4 (and possibly time 3) to show this is where most of the force interaction between the box and the track is occurring. We could add a red circle on the bottom of the wheels on the cart at time 2 (and possibly time 1) to show this is where most of the force interaction between the cart and the air is occurring. And we could add blue arrows to show that this is where energy transfer to the track is occurring.*

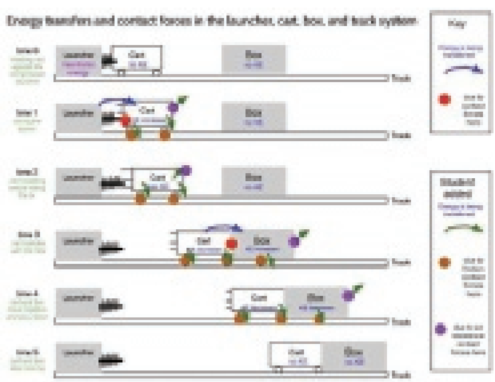
when you start tracking it into, through, and across systems and subsystems. In their descriptions of energy transfer in the class collision system model they should be able to describe qualitative gains and losses of energy between the subsystems within the cart launcher system model.

Additional Guidance

Students may bring up the idea of static friction by asking about forces between the cart or box and the track when they are not moving. This is OK, and you can ask what students think about forces between surfaces that aren't moving. You will return to considering net forces in future lessons. Accept all ideas at this time and say, *It sounds like we can use this idea of friction to explain why it takes a certain amount of force to get a stationary object to start moving too.*

Have students add annotations to their copies of *Energy transfers and contact forces in the launcher, cart, track, and box system* to represent these ideas. The example diagram shown here provides a key for some of the times and places you may see students adding these annotations to their model.

Display **slide I**. Say, *Let's update our Progress Trackers with these new ideas. In the Progress Tracker section of your notebook, make a three-part table to record the lesson question, sources of evidence, and what we've figured out.*



Have students add or move their copies of *Energy transfers and contact forces in the launcher, cart, track, and box system* to this section of the Progress Tracker. If they can't because they already glued these into their notebooks, they can add a reference page number to this entry (e.g., "see page X of the notebook"). Encourage students to use the remaining time to add descriptions in words for what they figured out that is represented in the system model we developed as a class.

8. Navigation

4 MIN

Materials: *Modeling other force interactions in the launcher, cart, box, and track system*, colored pencils, *Key for modeling force interactions in the launcher, cart, box, and track system*

Say, *Wow, we have really made progress on our model and filled in a lot of gaps to show what's happening in the system before, during, and after a collision. We accounted for forces and energy changes when parts of our system are speeding up, slowing down, and colliding. We also figured out a lot about what can contribute to damage in a collision. Let's take stock of what we know next class and see if we can explain why some objects break or don't break in a collision.*

Introduce the home learning. Say, *In preparation for that, look back at the previous models and explanations you developed in the last lesson and consider what you would change about them now in light of what you figured out in this lesson.*

Distribute the previously completed copies of *Modeling other force interactions in the launcher, cart, box, and track system* you collected from students at the end of the last lesson. Show **slide J**. Emphasize that the revisions that students should make to this handout are a key Assessment Opportunity for them to demonstrate what they figured out between the first time they completed this handout and now. Tell students that you will collect these next time.*

Assessment Opportunity

Building towards: 9.C Develop and revise a model to identify other parts of the system the cart and box are making contact with or colliding into that are producing contact forces on these subsystems, causing energy to be transferred to or from them as the box and cart travel down the track.

What to look for: See *Key for modeling force interactions in the launcher, cart, box, and track system* for guidance on what to look for.

What to do: Treat this as a way to measure student growth in understanding from the previous copy you made of their responses at the end of Lesson 8 and the start of Lesson 10. Since you won't have time to review their revisions until the end of day 1 of the next lesson, make sure you do that at some point during day 2 of the lesson, and definitely before day 3 of the lesson, so you can identify students who would benefit from talking through revisions to their models before working on the transfer task assessment items in *Baseball Assessment 1* and *Baseball Assessment 2*.

Alternate Activity

Instead of assigning this as home learning, you could use this revision activity as a bell ringer at the start of the next lesson.

SCIENCE LITERACY: READING COLLECTION 3

Kinetic Energy and Objects in Contact

1 Through Thick and Thin
2 What's Wrong with This Picture?
3 Human Tissues and Elastic Limits
4 The Danger Zone
5 Impossible Superhero Physics

Literacy Objectives

- ✓ Summarize key points related to energy of motion and objects in contact.
- ✓ Distinguish between credible and non-credible sources.
- ✓ Translate text to visual/graphic representation of ideas.

Prerequisite Investigations

Assign the Science Literacy reading and writing exercise *after* class completion of this lesson group:

- Lesson 6: What have we figured out about objects interacting in collisions? How can we apply our new learning to answer questions about objects interacting in collisions?
- Lesson 7: How much does doubling the speed or doubling the mass affect the kinetic energy of an object and the resulting damage that it can do in a collision?
- Lesson 8: Where did the energy in our launcher system come from, and after the collisions where did it go to?
- Lesson 9: How do other contact forces from interactions with the air and the track cause energy transfers in the launcher system?

Instructional Resources

Student Reader Collection 3	**Science Literacy Student Reader, Collection 3** "Kinetic Energy and Objects in Contact"
Exercise Page EP 3	**Science Literacy Exercise Page** EP 3

Literacy Activities

- Read varied text selections related to the topics explored in Lessons 6–9.
- Evaluate the reading selections according to provided prompts and criteria.
- Compare and contrast information gained from reading text with information gained from class investigation.
- Prepare a meme in response to the reading.

Standards and Dimensions

NGSS

Disciplinary Core Ideas

PS2.A: Forces and Motion The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. (MS-PS2-2)

PS3.B: Conservation of Energy and Energy Transfer When the motion energy of an object changes, there is inevitably some other change in energy at the same time.

Science and Engineering Practice: Obtaining, Evaluating, and Communicating Information

Crosscutting Concepts: Cause and Effect; Energy and Matter; Scale, Proportion, and Quantity

CCSS

English Language Arts

RST.6-8.1: Cite specific textual evidence to support analysis of science and technical texts.

RST.6-8.2: Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions.

RST.6-8.6: Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text.

Core Vocabulary

Core Vocabulary: Core Vocabulary terms are those that students should learn to use accurately in discussion and in written responses. During facilitation of learning, expose students repeatedly to these terms. However, these terms are not intended for isolated drill or memorization.

air resistance **friction**

kinetic energy

Language of Instruction: The Language of Instruction consists of additional terms, not considered a part of Core Vocabulary, that you should use when talking about any concepts in this exercise. Students will benefit from your modeling the use of these words without the expectation that students will use or explain the words themselves.

concussion **fluid**

law of conservation of energy **projectile**

resistance **symmetrical**

A Glossary at the end of the Science Literacy Student Reader lists definitions for Core Vocabulary and selected Language of Instruction.

1. Plan ahead.

Determine your pacing to introduce the reading selections, check in with students on their progress, and discuss the reading content and writing exercise. If you are performing Science Literacy as a structured, weekly routine, you might implement a schedule like this:

- Monday: Designate a ten-minute period at the beginning of the week to introduce students to the assignment.
- Wednesday: Plan to touch base briefly with students in the middle of the week to answer questions about the reading, to clarify expectations about the writing exercise, and to help students stay on track.
- Friday: Set aside time at the end of the week to facilitate a discussion about the reading and the writing exercise.

Exercise Page

EP 3

2. Preview the assignment and set expectations.

(MONDAY)

- Let students know they will read independently and then complete a short writing assignment. The reading selection relates to topics they are presently exploring in their Contact Forces unit science investigations.
- The reading and writing will be completed outside of class (unless you have available class time to allocate).
- Preview the reading. Share a short summary of what students can expect.
    - *In the first selection, you will read an article from a mock popular science website about factors that affect how easily objects move through fluids—air and water.*
    - *Next, you'll look at the path that a projectile takes once it is launched in air versus no air, from a faux educational website.*
    - *Then, you'll read a simulated sports article about how collisions and forces in sports affect the human body.*
    - *Next, you'll read two simulated online articles that apply the laws of motion to car crashes, highway design, and brain injuries in sports. The latter is followed by simulated online comments from readers.*
    - *Lastly, you'll read a mock blog about the movies that explains how superhero movies break the law—that is, the law of conservation of energy and the laws of motion.*
- Distribute Exercise Page 3. Preview the writing exercise. Share a summary of what students will be expected to deliver. Emphasize that Science Literacy exercises are brief. The focus is on thoughtful quality of a small product, not on the assignment being big and complex.
    - *For this assignment you will be expected to generate a draft internet meme to communicate an important message about the laws of motion and human safety.*
- Remind students of helpful strategies they can employ during independent reading. Offer the following advice:
    - *The reading should take approximately 30 minutes to complete.* (Encourage students to break reading into smaller sections over multiple short sittings if their attention wanders.)
    - *A good reading strategy is to scan through the collection first to see the titles, section headers, graphics, and images to see what the selections are going to be about before fully reading.*
    - *Next, "cold read" the selections without yet thinking about the writing assignment that will follow.*
    - *Then, carefully read the Exercise Page to understand the expectations for the writing part of the assignment.*
    - *Revisit the reading selections to complete the writing exercise.*
    - *Jot down any questions for the midweek progress check in class.* (Be sure students know, though, that they are not limited to that time to ask you for clarification or answers to questions.)

3. Touch base to provide clarification and address questions. (WEDNESDAY)

Touch base midweek with students to make sure they are on track while working independently. You may choose to administer a midweek minute-quiz to give students a concrete reason not to postpone completing the reading until the last minute. Ask questions such as these, and have students jot answers on a half sheet of paper:

Suggested prompts	Sample student responses
What is another name for air resistance?	*drag*
How does air resistance affect the path of a moving projectile?	*It may reduce the height and distance an object will travel.* *It may make the projectile's path asymmetrical.*
How does velocity affect the force of a car collision?	*The greater the velocity of the car, the greater the force of the collision.*

Ask a few brief discussion questions related to the reading that will help students tie the text content to students' classroom investigations.

Suggested prompts	Sample student responses
In what direction does friction apply contact forces to a moving object?	*It applies forces in a direction that is opposite to the direction of motion.*
From the patterns you saw in Lesson 7, what can you predict about the effect of doubling the speed of a car on its kinetic energy?	*Doubling the speed results in quadrupling the kinetic energy of the car.*
What factors do you need to consider when comparing the amount of kinetic energy involved in a collision of two soccer players?	*the speed of each player and the mass of each player*

- Refer students to Exercise Page 3. Provide more specific guidance about expectations for students' deliverables due at the end of the week. See the **Online Resource Guide** for a link to examples of memes if that would be helpful. **www.coreknowledge.org/cksci-online-resources**
  - *The writing expectation for this assignment is to create a draft internet meme that can be copied and shared to make people think about motion, energy, and collisions and how they relate to activities that can affect their ability to stay safe.*
  - *That means you'll craft your meme to make people stop and think when they see it.*
  - *Think about your audience as being other students in your school.*

Exercise Page

EP 3

Online Resources

- *If you want your meme to go viral and influence people's behavior, make it eye-catching and current.*
- *Play with your words in an intriguing way—intentional slang is okay.*
- *While most internet memes have photos, this assignment only requires a drawing. Drawing skill is not required—stick figures and simple outlines can work, too.*
- *The important criterion for your meme is that it displays your new understanding of energy, collisions, and safety with just a picture and a few words.*

- Answer any questions students may have relative to the reading content or the exercise expectations.

4. Facilitate discussion.

(FRIDAY)

Facilitate class discussion about the reading collection and writing exercise. In the first selection, students will learn answers to some interesting questions, such as, *Why are sharks shaped like a jet plane?* and *Why do jet planes fly so high above Earth's surface?*

Pages 24–33 **Suggested prompts**	**Sample student responses**
What is the general purpose of the first selection, "Through Thick and Thin"?	*It explains how objects moving through liquids and solids encounter resistance to their motion due to friction and that jets fly at altitudes where the air is less dense and then use gravity to pull them down to land.*
How would the density of a one-cubic-meter box filled with water vapor compare to the same box filled with liquid water?	*The water vapor would be less dense because there is less matter than in an equal volume of liquid water.*
How does a jet plane's potential energy change during a flight?	*Its potential energy increases as it climbs higher and decreases as it descends.*
In Lesson 8, how did you increase the amount of potential energy in a spring?	*by compressing it or stretching it*
What is the general purpose of the second selection, "What's Wrong with This Picture?	*It explains the shape of the path of a projectile in the presence of air resistance.*
How does the second selection help you build knowledge on top of what you learned in the first selection?	*The first article explains what air resistance is. The second article details the effect of air resistance on the path of a projectile in air and in a vacuum.*
What did the writer mean by saying the path of a ball is symmetrical?	*that the shape of the path on the way up to its highest point is the mirror image of the shape of the path on the way down*

Student Reader

Collection 3

SUPPORT—If you are using the recommended word envelope convention, check the envelope to see if it contains any words, phrases, or sentences that students need help understanding. Read key sentences aloud, and provide concise explanation.

SUPPORT—Remind students that the scientific term *fluid* includes all gases and liquids and that all fluids can flow when a force is applied to them. Have students brainstorm a list of other fluids, in addition to water and air, such as motor oil, gasoline, honey, helium gas, and neon gas.

Pages 24–33 **Suggested prompts**	**Sample student responses**
What is the general purpose of the third article, "Human Tissues and Elastic Limits"?	*It describes what happens to human tissues when they reach their elastic limits.*
How does this selection help you build knowledge on top of what you learned in Collection 2?	*In Collection 2, we learned what a tendon is and that tendons can tear if they lose elasticity. In this reading, we learn more details and the kinds of sports situations that may cause tendons to strain or tear.*
Based on your work in Lesson 7, explain the relationship between peak forces and elastic limits in basketball Achilles tendon injuries.	*When the basketball player is in a collision in which the peak force is greater than the elastic limit of the Achilles tendon, that tendon will be damaged—either strained or torn.*
What is the general purpose of the fourth article, "The Danger Zone"?	*The first three pages are science articles about how the laws of motion are involved in car collisions and in sports collisions and the damage such collisions are likely to cause. The last page is a social media discussion about whether headers should be banned from youth soccer.*
How do the text and graph on page 29 support one another? Which did you find easier to understand?	*They give very similar information, but I found the graph easier to understand than the text.*
Look at the Consider the Source box on page 29. What inferences can you draw about the source and the data in the graph?	*that a federal government agency collected the data and built the chart and so it likely includes reliable data from all 50 states* *that the agency is interested in saving lives* *that the agency may recommend that law enforcement stop speeders more often* *that the data is a bit old, having been collected in 2014, or that the research is only done every few years*
Look at the Spot the BS box on page 30. Where did you find the misunderstanding of Newton's second law of motion?	*Grant Childs said, "Little kids' heads are so small and light, they don't get concussions as bad as adults anyway. Not much mass, so the force can't get very high." This ignores that the mass and acceleration of the moving ball hitting a kid's head can still be damaging. (Also, a kid's smaller bones are likely more at risk of damage.)*
What is the general purpose of the fifth article, "Impossible Superhero Physics"?	*It explains why you need to put aside your understanding of the law of conservation of energy and Newton's laws of motion to enjoy a superhero story.*

SUPPORT—Give English learners a tactile activity to learn what *symmetrical* means. Have them fold a sheet of paper in half and use scissors to cut an arc from the lower corner of the unfolded edge to the upper corner of the folded edge. When they open the paper, show them how the two arcs are mirror images of one another.

CHALLENGE—Have interested students write their own reply to the social media posts in selection 4. Encourage them to express their opinions on whether students their age should be allowed to make headers when playing soccer, referring to the science in support of their argument.

Pages 24–33 Suggested prompts	Sample student responses
How does the previous reading selection help you understand this selection?	*The fourth selection explains that net force equals mass times acceleration (and what "acceleration" means). That helped me understand that a kid who has little mass and is not moving does not have enough force to stop the net force of a train.*
Using the context of the second-to-last paragraph as a guide, state the law of conservation of energy.	*In a closed system, energy cannot be created, only converted from one form to another, such as from sunlight into electrical energy.*

5. Check for understanding.

Evaluate and Provide Feedback

For Exercise 3, students should draft a thought-provoking internet meme that connects their understanding of energy, collisions, and forces to a human safety issue. See an example shown for a reference to brain injuries from soccer headers. Other memes may highlight Achilles tendon injuries or automobile safety. Limit your evaluation of design to image content and use of lettering, but avoid commenting on students' drawing ability.

Use the rubric provided on the Exercise Page to supply feedback to each student.

Online Resources

EXTEND—If students want to use their sketched drafts to create a finished product, allow them to use a drawing application, or point them to smartphone or online meme generators with templates they can edit and step-by-step directions for creating, downloading, and sharing their memes. Check the age requirements, content for vulgarity, and privacy policy of any tool to make sure it conforms with your school's internet-use policies.

Why do some objects break or not break in a collision?

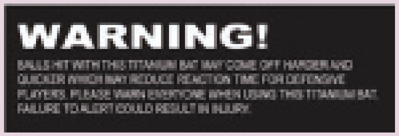
Previous Lesson

We conducted investigations to gather evidence to explain what other forces affect the kinetic energy of an object before a collision. We developed claims using our evidence and provided and received feedback with peers to synthesize our ideas. We revised our model to show additional places in the launcher system where energy is transferred and how contact forces cause this energy transfer.

This Lesson

Putting Pieces Together

2 DAYS



We revisit our collision types from Lesson 1 and explain why some objects were damaged and others weren't in different collisions. We use these ideas to answer questions on the Driving Question Board and take an assessment to apply our new ideas to a new set of collision-related phenomena in the context of baseball.

Next Lesson

We will revisit our anchoring phenomenon and discover that some phones were in cases when they were damaged. We will develop new phone case criteria and constraints and design a protection device for something new. We will receive design feedback and develop an encompassing set of criteria and constraints.

Building Toward NGSS

MS-PS2-1, MS-PS2-2, MS-PS3-1, MS-ETS1-2, MS-ETS1-3, MS-LS1-8

What Students Will Do

10.A Apply scientific ideas to explain why some collision-related phenomena resulted in damage while others did not and to explain how the contributing factors (energy, matter, peak forces) could change to result in different collision outcomes.

10.B Apply scientific ideas to explain multiple baseball phenomena, including the effects of air density and wind on ball speed (changes to the stability of the system and its effect on kinetic energy changes due to air resistance), bat mass vs. bat speed (interpreting patterns in graphical and tabular data to determine the linear and nonlinear effects on increases of kinetic energy within the system), and bat type (the effect deformation has on peak forces in the system and kinetic energy) on how the game is played.

What Students Will Figure Out

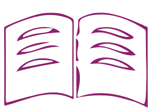
We figure out these ideas:

- We have made progress on our DQB questions.
- We can apply our new learning over mass, speed, peak forces, and energy transfer to explain equipment-related collisions and interactions in baseball.

Lesson 10 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	10 min	**NAVIGATION** Reflect on prior learning and take stock of big ideas.	A	Big Ideas poster, markers
2	12 min	**REVISIT AND EXPLAIN COLLISION TYPES** Revisit the Different Collisions poster from Lesson 1 and explain each collision type in small groups.	B-C	*Explaining a Collision*, optional: a completed version of *Related Phenomena List*, Different Collisions poster from Lesson 1, Related Phenomena poster from Lesson 1, Big Ideas poster
3	10 min	**RECEIVE PEER FEEDBACK** Receive feedback on question 3 from partners with the same collision type and with different collision types.	D-E	*Explaining a Collision*, 1 timer
4	3 min	**NAVIGATION** Look ahead to revisiting the DQB and the assessment.		
				End of day 1
5	15 min	**REVISIT THE DQB** Use the Big Ideas poster to help answer questions on the DQB.	F	optional: typed list of DQB questions from Lesson 6, *Big Ideas Table*, Big Ideas poster
6	30 min	**LESSON 10 ASSESSMENT** Begin Lesson 10 assessment.	G	*Baseball Assessment 1* or *Baseball Assessment 2*
				End of day 2

Lesson 10 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide**  **Student Work Pages** 	• science notebook • *Explaining a Collision* • optional: a completed version of *Related Phenomena List* • optional: typed list of DQB questions from Lesson 6 • *Big Ideas Table* • *Baseball Assessment 1* or *Baseball Assessment 2*		• Big Ideas poster • markers • Different Collisions poster from Lesson 1 • Related Phenomena poster from Lesson 1 • 1 timer

Online Resources

Materials preparation (20 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Note about Materials: *Baseball Assessment 2* is an alternate for *Baseball Assessment 1* and asks students to create the axes labels and intervals for the graph in question 4. *Baseball Assessment 1* is the default assessment. *Baseball Assessment 2* would take a bit longer and may be a bit more challenging for some students. If some students need a more challenging assessment, give only those students a copy of *Baseball Assessment 2* instead of *Baseball Assessment 1*. All other students should only receive a copy of *Baseball Assessment 1*. Make a copy of one of these assessments, but not both, for each of your students depending on the level of challenge or differentiation needed for each student.

Day 1

- Create a poster titled “Big Ideas”.
  - If desired, the What We Have Discovered poster from Lesson 6 can be reused and expanded upon with the big ideas from Lessons 7-9 instead of creating the new Big Ideas poster.
  - Note that the ideas on the What We Have Discovered poster will be more detailed than intended for this activity, but they may be more helpful for students who need extra support.
- Create on chart paper a Related Phenomena List:
  - Organize the list with collision type headers.
  - Note whether the object was damaged or not damaged under the collision type headers.
  - *Related Phenomena List* can be used as a template to create this list.

Day 2:

- Optional: Have copies of the Driving Question Board questions ready for students to reference (previously used and collected at the end of Lesson 6).
- If some students need a more-challenging version of the assessment, substitute out copies of *Baseball Assessment 1* for copies of *Baseball Assessment 2* for those specific students. All other students should receive only a copy of *Baseball Assessment 1*.
- If some students will need additional scaffolds to complete *Baseball Assessment 1*, make copies of *Big Ideas Table* for those specific students.

Lesson 10 • Where We Are Going and NOT Going

Where We Are Going

This lesson provides an opportunity for students to apply new learning gained in Lessons 7–9 as well as another opportunity to reapply the ideas developed in Lessons 2–6. Students use these ideas to explain specific phenomena they identified from their prior experiences that fall into the categories for the three collision types identified in Lesson 1 and explain how factors in each collision type (increases and decreases in speed, mass, kinetic energy, friction, air resistance, and peak force) contribute to damage or no damage in the collision between two objects. Students also apply their ideas to answer questions on the Driving Question Board. Students then apply their knowledge to answer questions on an assessment targeting PS2.A (The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. Forces on an object can also change its shape or orientation.) and PS3.A (kinetic energy . . . is proportional to the mass of the moving object and grows with the square of its speed).

Where We Are NOT Going

Some students may discuss the role of some materials in protecting objects better in a collision. But students will not develop or use ideas related to the structures and properties of protective materials until the next lesson and the remainder of the unit (Lesson Set 3). Students who are familiar with baseball may bring up the idea of the "sweet spot" on the bat that can affect the way a ball behaves. This lesson will not cover this topic as this behavior is related to something known as the center of percussion, which deals with both the elastic and harmonic properties of the bat that are above the grade-band targets for the disciplinary core ideas in middle school. Explaining how wind speeds in the direction of motion (tailwinds) also is not assessed, nor is the role of gravity in the motion of the ball, nor how the interactions with the air can cause lift (or downward forces) on the ball when it is rotating. Quantitative calculations of forces based upon wind speed and direction and air density are above grade band and not the focus of this lesson.

LEARNING PLAN FOR LESSON 10

1. Navigation

10 MIN

Materials: science notebook, Big Ideas poster, markers

Reflect on previous lessons. Say, *Well, it seems like we have done a lot of work learning about the factors that can affect the motion of objects and what occurs when objects make contact in a collision. We know all these factors contribute to the potential for damage in a collision. Let's look back at our previous work as a class and create a list of our big ideas about these factors that affect the potential for damage in a collision.*

Display the Big Ideas poster that was made prior to class. Project **slide A**. Place the Big Ideas poster in front of the class. Ask students to look back in their notebooks to their Progress Trackers at what they recorded for their last lesson. Explain that as students share what we have learned, you will record the big ideas on the Big Ideas poster.*

Ask students, *What was a big key take-away from our last lesson?* Students should respond with the following ideas:

- Friction and air resistance are contact forces.
- Friction causes energy to be transferred to and from objects as they come into contact with each other.
- Friction and air resistance decrease the kinetic energy of the moving object but increase the kinetic energy of the particles that make up the objects or subsystems the moving object comes into contact with (as well as on some of the surfaces of the moving object as well).

*** Attending to Equity**
Universal Design for Learning: This activity of co-constructing a list of the big ideas or take-aways students will have figured out up until this point in the unit is in service of recalling concepts developed in the prior lesson(s) so that students can readily apply these ideas to developing their own models that connect the ideas together to explain their own phenomena from Lesson 1.

When creating this list, make sure that the list gives the opportunity for students to *engage* by

Take a moment to summarize into a shortened bullet point what students are saying:

- Friction and air resistance affect a moving object's kinetic energy.

Say, *We also have some great ideas from Lesson 8 that we had discovered. What did we learn in Lesson 8 that we can include in our Big Ideas list?*

Continue the process of having students share what we have learned as you summarize them into quick bullet points for students to reference. Below is a list of bullet points by lesson as an example:

Lesson	Big Ideas
9	• Friction and air resistance can affect a moving object's kinetic energy.
8	• Objects with different speeds and masses require different amounts of force to speed them up or slow them down. • Energy can be transferred into or out of an object when it comes in contact with another object due to the forces that act on each object. • It takes more force to speed up a more-massive object the same amount as a lower-mass object.
7	• The more kinetic energy an object has, the more damage that object can do in a collision. • Changes in the kinetic energy of a moving object are proportionally related to changes in the mass of that object. • Changes in the kinetic energy of a moving object are related to changes in the speed of that object.
6	• putting the pieces together and assessment—an application in the context of soccer of the ideas we developed earlier in the unit
5	• Forces are applied on both objects in equal strength and opposite directions during a collision. • Speed and mass increases lead to kinetic energy increases, which can lead to higher peak forces.
4	• All objects deform up to a point. • Once their elastic limit is reached they permanently deform. • Different materials, shapes, and thicknesses result in different elastic limits and breaking points for different objects.
3	• All objects bend or change shape in a collision.
2	• Collisions can cause shape and motion changes. • Energy transfers in a collision. • There are forces in a collision.

optimizing the challenge for some students or varying the amount of detail used in the list for others. Err on the side of general bullet points when creating this list to allow students to show that they understand the concept, in lieu of re-writing the concept on the list as their answer.

If the list on this poster is too specific, some wording of aspects and ideas could be copied directly from the poster onto the student-created models, limiting the amount of actual idea transfer and *representation* that would occur in the next step for students who are ready to engage in a higher level of application of the science ideas. Alternatively, if a student is in need of an additional scaffold, a list with more-detailed ideas could be given to the student during the modeling process, such as the more detailed list from the What We Have Discovered poster from Lesson 6. A less detailed list allows students who are not in need of the additional scaffold to still show their application of ideas, and a more detailed list helps those who need the scaffold receive the just-in-time support.

Additional Guidance

Lessons 7–9 build upon learning from Lessons 2–6. Some classes may mention ideas from Lessons 2–6 as they are referencing ideas developed in Lessons 7–9. These classes or students may not need to go back as far as Lesson 2 to encapsulate the big ideas in their big ideas list. This is fine as long as these ideas from Lessons 2–6 are also present in the final Big Ideas poster.

Alternate Activity

If desired, the What We Have Discovered poster from Lesson 6 can be reused and expanded upon with the big ideas from Lessons 7–9 instead of creating the new Big Ideas poster. Note that the ideas on the What We Have Discovered poster will be more detailed than intended for this activity, but they may be more helpful for students who need extra support. The What We Have Discovered poster would also be helpful for those who are still mastering the ideas presented in Lessons 1–6. If this option is chosen, substitute out the Big Ideas poster references in this document for the What We Have Discovered poster.

2. Revisit and explain collision types.

12 MIN

Materials: *Explaining a Collision*, science notebook, Optional: a completed version of *Related Phenomena List*, Different Collisions poster from Lesson 1, Related Phenomena poster from Lesson 1, Big Ideas poster

Say, *Now that we have this great list of the big ideas we've discovered so far, let's see if we can apply these to explain collisions from Lesson 1. Let's look back at our Different Collisions poster.*

Look back at the Different Collisions poster. Project **slide B** if students cannot see the Different Collisions poster well from their seats. Direct students to look at the Different Collisions poster. Point out that we had categorized 3 main types of collisions:

- Collision type A: A moving object was damaged OR wasn't damaged when it collided with a motionless object.
- Collision type B: A motionless object was damaged OR wasn't damaged when a moving object collided with it.
- Collision type C: A moving object was damaged OR wasn't damaged when it collided with another moving object.

Ask students if they think we can better explain why some objects broke in those collisions and others did not. Students should respond positively to this question.

Say, *We will have a chance to revisit each collision type in small groups. Remember, we brainstormed related phenomena that went with each collision type in Lesson 1. We should go back and try to explain our real-world scenarios! We know that we cannot individually easily explain each and every collision mentioned on our Related Phenomena poster ourselves, so we can each pick one collision type and pick a related phenomenon that falls into that category. That way we can explain multiple collisions in one class period.*

Apply these big ideas to another collision phenomenon. Project **slide C**. Distribute *Explaining a Collision*. If the printable copy of *Related Phenomena List* was created in lieu of the Related Phenomena List on chart paper, pass it out at this time. Explain that *Explaining a Collision* will help them explain what happens before and during a collision that can contribute to damage or no damage occurring to the objects involved. Tell students that in a moment they will be divided into groups of 3, and each person will take a collision type to work with. The projected handout on slide C can be used to point out specific questions as the class goes over the handout together. On question 1 they will select which collision type they are individually focusing on in their groups. After the groups have delegated collision types, they will then get to choose their own collision from the Related Phenomena List or the printed copy of *Related Phenomena List* that has all of our different collisions listed from the Related Phenomena poster. On question 2, students will write what they have chosen as their related phenomena collision.

Point out that question 3 has a 3-series box that will need to be completed. The boxes are broken down into 3 basic categories:

- Box 1- factors that impact movement before the collision
- Box 2- what occurs during the collision to cause damage or no damage
- Box 3- what factors would be altered to have the opposite outcome in a collision

Go over instructions for each box in question 3. Look closer at box 1 with students. Say, *We now know that a lot of factors affect the objects before a collision. We also know that those factors affect the objects' kinetic energy, which in turn will affect their potential for causing or experiencing damage in a collision. In box 1, make sure to draw a free-body diagram of each moving object and each nonmoving object. Be sure to show what factors affect the object before it comes into contact with the other object in a collision.*

Move on to box 2 with students. Begin a discussion about whether to include forces such as friction and air resistance in box 2. Lead students to understand that this is not a needed part of the collision drawing for box 2. Example prompts and responses for this discussion are below:

Suggested prompts	Sample student responses
Let's think about some of the factors from box 1. What are some of the things from our Big Ideas list that we may want to add in that box as impacting the movement of objects before the collision?	*Friction of the ground.* *The air resistance.*
Looking at box 2, do we think that these forces are also working during our collision?	*Yes, friction on the ground or air resistance is almost always acting on a moving object.*
Do we think that friction and air resistance are causing things to break or not break when the two objects are in contact in box 2? Are friction and air resistance causing the potential damage, or is that the contact forces?	*The friction and air resistance affect how it moves, but don't affect the object that much when it collides.* *The forces that really cause damage are the contact forces during the collision.*
So in box 2, does it make sense to focus on the forces of friction and air resistance, or on the contact forces?	*It makes more sense to focus on the contact forces, since those lead to damage or no damage.*

Say, *OK, so friction and air resistance are probably still at play on the objects during a collision, but the collision occurs over such a brief period of time that those forces are relatively weaker than the other contact forces in most collisions, so since they don't really affect those objects as much as the other contact forces in a collision, let's make sure that in box 2 we just focus on those contact forces that occur during the collision.*

Instruct students to make a note of this beside box 2 if they feel they will need a reminder of this decision later.

Look at box 3 more closely with students. Explain that this box is meant for students to consider what factors would have to be changed to alter the outcome of the collision. If the object(s) did not break, explain what changes to the objects would have to occur to create damage in the collision. If the object(s) was damaged, explain what changes to the objects would have to occur to lead to no damage in the collision. In the latter case, make sure students know that they are drawing and explaining changes to the objects' force and energy and not adding any protective materials or any other physical materials to the objects that have the function of protecting the object(s). Box 3 is asking what force and energy changes would have to occur to the objects to create a different outcome in the collision.

Group students and begin the task. Divide students into groups of 3. Remind students that each person in the group will be working on a different collision type. Before students start working, go to each group and confirm that each student is delegated a different collision type. Tell students that as they work they should reference the Big Ideas list and use their science notebooks as a reference to complete the task.

As students are working, circulate from group to group. Use this time to provide individual feedback in the form of questioning to guide students to the big ideas and representations needed in each box. The following questions can be used to help students as they are working on different boxes:

Box #	Questions to use
1	• What factors did we identify on our Big Ideas list that we can include in box 1? • What did we say impacts the movement of objects before the collision? • Think back to Lessons 7 through 9. How did we represent those ideas? Did we represent them the same way here? • Did you make sure to show both objects and also show how different forces affect their motion before the collision?
2	• Did you make sure to only focus on the forces and energy changes that cause damage in a collision? • What happens to the structure of objects during a collision? • What made your object break or not break? Make sure to include that in box 2. • Are all the ideas about the moment of collision from our Big Ideas list in box 2?

Box #	Questions to use
3	• Look back at box 1. If something were different in box 1, would it affect the collision? If so, document that in box 3. • Are there any forces that act on the object before or during the collision that could be changed to affect the outcome of the collision? Which ones? Add those to box 3. • Look back at box 2. If you were to alter something in box 2, would it affect the outcome of the collision? If so, add it to box 3.

When students believe they are finished, use these questions to help them check their ideas:

- Are the ideas on our Big Ideas list somewhere in your explanation in question 3?
- Double-check kinetic energy. Are you showing the correct changes in kinetic energy from box 1 to box 2?
- Check with another group member. Do you have similar ideas in boxes 1 and 2?

Allow students time to finish *Explaining a Collision*. Encourage them to compare ideas on question 3 with their group members as they complete their work.

3. Receive peer feedback.

10 MIN

Materials: *Explaining a Collision*, 1 timer

Introduce collision type partner feedback process. Display **slide D**. After students have completed a first pass at filling out *Explaining a Collision*, tell students that they will get a chance to give and receive feedback on their ideas. Explain to students that they will find a person from another group with the same collision type. They will then share their specific phenomenon and show how they represented their ideas for question 3. After that, they can discuss similarities and differences in their representations and overall ideas using the guiding questions on slide D.

Say, *After you have had a chance to share with your partner, you will get a chance to revise your ideas and make a stronger explanation based upon what you may have seen in your partner's model or the feedback that your partner has given you. We will have a chance to get feedback twice, this time from someone with our same collision type, and then from someone with a different collision type. After we have completed our revision cycles, you will be turning this in.*

Tell students that you will set a timer for 5 minutes to complete this feedback process. To help students find someone else who has the same collision type, ask students who have collision type A to raise their hand. Have students with their hands raised point to the person that they are going to engage in the feedback process with. It is OK to have one group of 3 if there is not an even number of students with that collision type. Repeat this selection process with collision types B and C. Once all students have a partner, instruct them to find a spot next to their partner and start the feedback process.

As students are giving feedback, circulate and remind students to use the guiding questions on the slide to help give feedback. After both partners have explained their ideas and given feedback, remind students to make any changes they feel necessary based upon the feedback they have received to question 3. Once students have completed this process, have them return to their seats.

Introduce the partner feedback process with a different collision type. Explain to students that now that we have had a chance to think about our own collision types, we also know certain factors can change the amount of damage in different collision types. A collision with just one moving object may have different interactions during the moment of contact than a collision with more than one object moving. Things like peak force, resistance, and kinetic energy may be shown differently for different collision types. Because we want to consider how different collisions result in damage or no damage, we really need to discuss our ideas with someone else who had a different collision type than the one we just explained. This may also help us explain more about the factors that might contribute to more or less damage in box 3.

Project **slide E**. Tell students that the feedback process will be the same as the last round, with the exception of their partners and a couple of the questions. This time they will find someone who has a different collision type from a different group to share their ideas with. After both partners have shared their ideas, they will work together to answer the feedback questions on slide E and revise their ideas on question 3.

Have students get up from their seats and find someone who has a different collision type. Once students have found someone with a different collision type, students should start the feedback process using the questions on **slide E**. After both partners have explained their ideas and given feedback, remind students to make any changes to question 3 they feel necessary based upon the feedback they have received.

After the students have completed their feedback and the revision of question 3, have them hand in *Explaining a Collision*. Use this handout to gauge student understanding of variances that can occur to impact damage in a collision.

Assessment Opportunity

Building towards: 10.A Apply scientific ideas to explain why some collision-related phenomena resulted in damage while others did not and explain how the contributing factors (energy, matter, peak forces) could change to result in different collision outcomes.

What to look/listen for: Look for students to use the ideas off of the Big Ideas poster. In box 1, look for these ideas:

- representing the kinetic energy of the moving object as greater than the nonmoving object
- forces due to air resistance and friction acting on the moving object before the collision
- force arrows that are representative of the relative amounts of force acting on the moving object in the proper direction and whose arrow tips are touching the surface the force is acting on

In box 2 look for these ideas:

- objects bending or deforming (momentarily or permanently)
- each object experiencing the same amount of peak force but in opposite directions
- energy being transferred in the system between the colliding objects at the moment of contact
- optional: If the objects are made of different materials, they could show different amounts of deformation for the same amount of force. Though students know this should be the case based on ideas they figured out in Lesson 4, because they won't know the relative elasticity of each object in the system, they may not feel it is valid to represent these relative differences in their models without having these specific data to inform which object would deform more or less than the other.

In box 3 look for these ideas:

- changes in speed being represented as a larger factor than changes in mass in reducing or increasing kinetic energy of the moving object(s)
- greater or less air resistance and friction causing the increase or reduction of kinetic energy of the moving object(s) before the collision
- changes listed above having an effect on the amount of deformation of each object at the moment of collision
- changes in the amount of deformation of each object corresponding to whether it exceeds the elastic limit of the object or not to account for whether it is damaged or not

What to do: As students hand in *Explaining a Collision*, check the handout for the ideas above. If an idea is missing or misrepresented, revisit the Big Ideas poster with the student(s) before the assessment on day 2. Use the Big Ideas poster for a checklist and make sure the student(s) sees that a concept is missing or that a concept may be misrepresented. Direct the student(s) to look back at representations in Lessons 6–8 that show changes in friction, air resistance, and kinetic energy. If the idea comes from Lesson Set 1, use the Lesson 6 What We Have Discovered poster as a physical checklist for the students. This more-detailed list may provide a needed scaffold for students.

If intervention at this stage is warranted, use the DQB check-in the next day as a secondary formative assessment. Ask questions specifically targeted to the related topics above from the DQB and have students turn and talk with a partner about their answers. Listen to those specific students who had required intervention to assess if they now are using the target understandings.

4. Navigation

3 MIN

Materials: None

Say, *Wow, we have really figured out a lot about collisions and damage! Next time, let's see if we can answer any more questions from our DQB and then apply what we have figured out to a new scenario—baseball!*

End of day 1

5. Revisit the DQB.

15 MIN

Materials: optional: typed list of DQB questions from Lesson 6, *Big Ideas Table*, Big Ideas poster

Say, *Last class we worked on applying our knowledge to explain how each collision type worked and why some collisions caused damage or not. Let's see if we can apply some of the ideas from our Big Ideas poster to answer more questions on our DQB.*

Project **slide F**. Ask students to meet in a semicircle around the DQB.* Have students turn and talk about the following questions:

- What areas of the DQB have we made progress on?
- Are there any specific questions that we can now answer that we could not answer last time?

*** Attending to Equity**
Universal Design for Learning: Some students may not be able to see the smaller writing of questions on the Driving Question Board or visually track from one question to another in a group of questions due to their *perception*. If students

Ask students to share whether we have made any progress on an area of the DQB. Students should respond that we have made progress on areas related to the movement of objects, friction, air resistance, damage, increases in mass vs. speed, peak forces, and KE. Pick one section that students feel we have made progress on and pull a question from that grouping. Read the question out loud and ask students what we can say is the answer to that question. Once the question is answered, put a check mark on the corner of the sticky note. If it is determined that all the questions in that section can be answered, place a larger check mark in the area of the section to indicate that the larger group has been answered. After a couple of individual questions have been answered from each section identified by students, start checking off full groups of questions that students feel we have made progress on.

After this process has been completed, most areas of the DQB should have large check marks next to them. There should still be a section remaining about materials and how those materials contribute to a reduction of damage in a collision. Point out this section to students.

Say, *It seems that we still have a section left over about materials and protecting objects. We will definitely have to revisit that and figure out how some materials work and seem to protect objects better than others. Figuring that out also seems to lend itself to an engineering approach to developing solutions that can help protect objects from getting damaged in a collision. But before we start down that path of questions and ways to investigate them, let's make sure we can apply our current understandings to another set of collision-related phenomena. Let's prepare to do that in the context of another sport, this time related to baseball.*

I found some interesting claims, data, and questions related to baseball game play that involve collisions. I'd love to share them with you and see if you can use what we figured out to explain these as well.

6. Lesson 10 Assessment

30 MIN

Materials: *Baseball Assessment 1* or *Baseball Assessment 2*

Distribute *Baseball Assessment 1* or *Baseball Assessment 2*. Project **slide G**. Read over the scenario with students. Direct students to put their name at the top of the paper and read through the questions together. Answer any clarifying questions students may have about the assessment.

Ask students to complete *Baseball Assessment 1* or *Baseball Assessment 2* on their own.* Collect the assessment when students are finished.

Alternate Activity

If students had previously needed additional learning experiences to show conceptual understanding on *Soccer Assessment* and have been revising their questions as the unit has progressed, instruct students to get out their prior assessment they have been updating during Lessons 7–9. Tell students to use their updated answers to aid them in developing their responses on the current assessment.

are having trouble seeing or would be better able to complete the task with a list of questions on paper in front of them, give students a copy of the typed DQB questions from Lesson 6. Students may have added questions to this list in the interim, but the Lesson 6 list will provide a great starting point for this DQB discussion. The list can also be modified and reprinted if desired.

Determine if you would like to give your class access to the Big Ideas poster while taking the assessment. If you would like students to complete the assessment without this, remember to take it down at this point in the lesson. Alternatively, if you would like only certain students to have access to this resource to *engage* them in deeper sensemaking during their assessment, consider making a copy to distribute to select students or allow students to access their notebooks during the assessment. A generic Big Ideas list can also be found in *Big Ideas Table*.

*** Attending to Equity**

Universal Design for Learning: There are two versions of this assessment to provide *access* for all students. Some students may be in need of additional scaffolds or more of a challenge during this assessment. If students need

Assessment Opportunity

Building towards: 10.B Students apply the science ideas to explain multiple baseball phenomena, including the effects of air density and wind on ball speed (changes to the stability of the system and its effect on kinetic energy changes due to air resistance), bat mass vs. bat speed (interpreting patterns in graphical and tabular data to determine the linear and nonlinear effects on increases of kinetic energy within the system), and bat type (the effect deformation has on peak forces in the system and kinetic energy) on how the game is played.

What to look for:

- Questions 1–2: Students should show a decrease in ball speed attributed to the loss of energy due to air resistance. Students should justify this idea using free-body diagrams showing the relative strengths of air resistance due to wind speed.
- Question 3: Students should use ideas for investigations that utilize previous labs and analogies made in class.
- Questions 4–6: Students will plot points based upon data, then predict a data point based on the line of best fit.
- Question 7: Students should explain that an increase in bat mass would decrease swing speed due to the amount of energy needed to move a more-massive object.
- Questions 8–9: Students should reflect an understanding that speed increases at a greater rate when kinetic energy is doubled. A decrease in air resistance would increase the visible effects of this relationship.
- Question 10: Students should argue the warning on the bat supports the coach's claim that it produces higher peak forces in a collision than other bats, but nothing on the warning provides information to support the claim that it deforms less in a collision.
- Questions 11–12: These answers are subjective to viewpoint; see *Key 1: Baseball Assessment* and *Key 2: Baseball Assessment*.
- See *Key 1: Baseball Assessment* and *Key 2: Baseball Assessment* for a more-detailed assessment guidance by question.

What to do: If students need additional assistance on

- questions regarding air resistance: If students are not showing air resistance as a force acting on the ball, revisit the question 1 wind speed graph with students and ask about the factors that could be affecting the ball during its flight. Compare the points on the graph and the axes labels to determine if energy is being lost to the air or gained from the air. Look back at Lessons 8 and 9 to view representations of how air resistance on the cart was modeled and consider how this can be applied to the current model.
- questions regarding plotting points: Revisit Lesson 9 and compare the plotted points seen on those graphs with the current graph students are constructing. Look at how the points are plotted on the *x*- and *y*-axes, and guide students in plotting the first point together.
- questions regarding the line of best fit and data identification: Revisit the second graph on *Station 2 data cards* and determine how the line of best fit was determined for each color on that graph. After establishing how the line of best fit is constructed, ask students to predict what the points would be at different speeds and fuel consumptions. Once students are more comfortable with finding potential data points based upon the line of best fit, have students again try to identify the data point in question 6.

additional support connecting the key ideas to the assessment, distribute *Big Ideas Table* and ask students to write the key idea that helped them answer the prompt (example: 8.b) next to the question. Use *Baseball Assessment 2* for students who would benefit from a more-challenging assessment. This assessment will provide less scaffolding for questions 3 and 4 than the other version.

- questions regarding the mass-energy relationship: Look back at the data from the Lesson 9 cart and box model and the Lesson 7 investigation data and graph regarding the increases in mass and kinetic energy needed to speed the object up to the same point. If this is not enough, pull the student aside and have them push two objects of different masses and determine which item would require more energy to get to the same speed. Have students apply this knowledge to the bat mass and swing speed questions on the assessment.
- questions regarding increases in mass vs. increases in speed: Revisit the data from Lesson 7 on *Changes in Kinetic Energy: Investigations #1 & 2* and *Graphing Kinetic Energy Relationships* to compare the relationships seen in the Lesson 7 data and the data on the assessment.

Additional Guidance

When evaluating student ideas on this assessment, it may appear that some students may need to receive additional support in understanding the science ideas. As interventions are being conducted that are listed in the "What to do" area of the assessment guidance and as students progress through Lessons 12–15, students may find value in the revision of their ideas. As the unit progresses, ask students to go back to *Baseball Assessment 1* or *Baseball Assessment 2* and revise their answers. Have students also look back at the Lesson 6 assessment and revise any ideas there as well. Students can then use these documents of evolving understanding to aid in their responses on the Lesson 15 assessment.

Say, *We have learned a lot about collisions, but we still seem to have questions about the materials in a collision. I was looking back at our phone-breaking problem and recalled some interesting data from our first lesson about phones that were protected and still broke! We will revisit those data in our next class.*

ADDITIONAL LESSON 10 TEACHER GUIDANCE

Supporting Students in Making Connections in ELA

CCSS.ELA-LITERACY.W.8.1: Write arguments to support claims with clear reasons and relevant evidence.

CCSS.ELA-LITERACY.W.8.1.B: Support claim(s) with logical reasoning and relevant evidence, using accurate, credible sources and demonstrating an understanding of the topic or text.

CCSS.ELA-LITERACY.SL.8.1.C: Pose questions that connect the ideas of several speakers and respond to others' questions and comments with relevant evidence, observations, and ideas.

Students write an explanation to support claims around mass and speed and how these affect the kinetic energy of a moving object. In addition, students revisit the Driving Question Board to identify what questions they can answer and which questions they still need to investigate.

LESSON 11

What can we design to better protect objects in a collision?

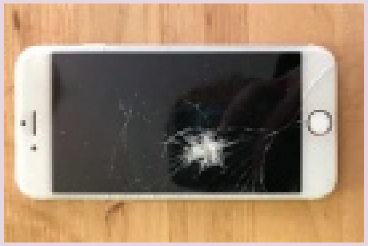
Previous Lesson

We revisited our collision types from Lesson 1 and explained why some objects were damaged and others weren't in different collisions. We used these ideas to answer questions on the Driving Question Board and took an assessment to apply our new ideas to a new set of collision-related phenomena in the context of baseball.

This Lesson

Anchoring Phenomenon

2 DAYS



We look back at our anchoring phenomenon and discover that some phones were in protective cases when they were damaged. We develop new phone case criteria and constraints and design our own protection device for something we want to protect. We receive feedback on our designs and consider what criteria and constraints all designs need to protect objects. We develop questions about our designs and ideas for investigation. We determine that we need to figure out the best damage-reducing materials.

Next Lesson

We will conduct an investigation to determine what materials reduce peak force in a collision and compare the structure of the materials. We will determine whether peak force is reduced equally on both objects, regardless of size, and try to develop a model to explain how the materials function to help reduce peak forces.

Building Toward NGSS

MS-PS2-1, MS-PS2-2, MS-PS3-1, MS-ETS1-2, MS-ETS1-3, MS-LS1-8

What Students Will Do

11.A Define a problem that can be solved with the development of a protective device to reduce damage (peak force) during a collision by identifying and considering multiple criteria and constraints along with specific materials, shapes, and designs of devices that reflect our science ideas of how certain material properties function in a collision.

11.B Design a solution to a problem to reduce the damage to an object in a collision (by reducing peak forces) by considering the properties of different, individual materials and shapes being used to serve particular functions.

What Students Will Figure Out

- All protection devices have similar criteria and constraints.
- Device shape, material, and structure have something to do with protective devices reducing damage to an object.
- We need to determine what makes certain materials better at reducing damage than other materials.

Lesson 11 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	10 min	**REVISIT ANCHORING PHENOMENON** Look back at phone case data from the anchoring phenomenon. Consider how to better protect phones from damage.	A-B	Building a Better Phone Case chart, markers
2	6 min	**CHART OTHER OBJECTS THAT NEED (BETTER) PROTECTION** Record what objects students believe need better protection during a collision and what changes can make that object more protected.	C-D	Objects that need (better) protection during a collision chart, markers
3	8 min	**DETERMINE CRITERIA AND CONSTRAINTS OF INDIVIDUAL DESIGNS** Select a personal object to protect and develop criteria and constraints for that object.	E-F	*Protection Device Design Thinking*, Objects that need (better) protection during a collision chart, Building a Better Phone Case chart
4	10 min	**DRAFT DESIGN IDEAS** Use *Drafting Our Protection Device Design* to draft the initial protective device designs.	G	*Protection Device Design Thinking*, *Drafting Our Protection Device Design*
5	11 min	**RECEIVE FEEDBACK ON DESIGNS** Introduce a structured feedback process to gain feedback on initial designs.	H-I	*Drafting Our Protection Device Design*, 1 timer
				End of day 1
6	13 min	**HOME LEARNING FEEDBACK GALLERY WALK** Look back at home learning to see what others would like to protect.	J-K	At least 3 3"x3" sticky notes for gallery walk feedback, *Drafting Our Protection Device Design*
7	8 min	**DEVELOP A SHARED CRITERIA AND CONSTRAINTS LIST** Work together to identify criteria and constraints that all designs should be structured around.	L-M	*Drafting Our Protection Device Design*, partner feedback sticky notes, Building a Better Phone Case chart, Whole-class Criteria and Constraints chart, markers
8	20 min	**DEVELOP QUESTIONS AND IDEAS FOR INVESTIGATIONS** Look back at the classroom artifacts and student artifacts to brainstorm questions and ideas for investigation related to structure, function, design, and materials.	N-O	3 more 3"x3" sticky notes, *Protection Device Design Thinking*, *Drafting Our Protection Device Design*, partner feedback sticky notes, Objects that need (better) protection during a collision chart, Building a Better Phone Case chart, Whole-class Criteria and Constraints chart, chart paper, markers
9	4 min	**NAVIGATION** Determine next steps to investigate what materials would make better protection devices.	P	
				End of day 2

Part	Duration	Summary	Slide	Materials
		SCIENCE LITERACY ROUTINE Upon completion of Lesson 11, students are ready to read Student Reader Collection 4 and then respond to the writing exercise.		Student Reader Collection 4: Materials, Design, and Outcomes

Lesson 11 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide** **Student Work Pages**	• *Protection Device Design Thinking* • *Drafting Our Protection Device Design* • At least 3 3″x3″ sticky notes for gallery walk feedback • partner feedback sticky notes • 3 more 3″x3″ sticky notes		• Building a Better Phone Case chart • markers • Objects that need (better) protection during a collision chart • Building a Better Phone Case chart • 1 timer • Whole-class Criteria and Constraints chart • chart paper

Materials preparation (15 minutes)

Online Resources

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

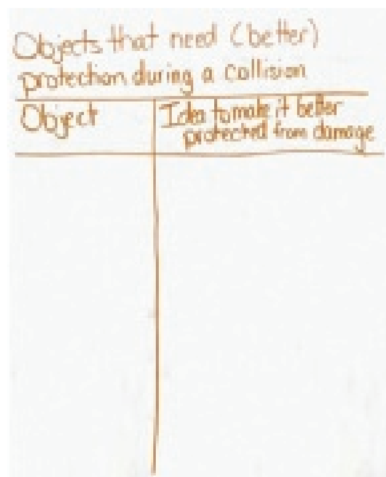
Create a chart titled "Building a Better Phone Case".

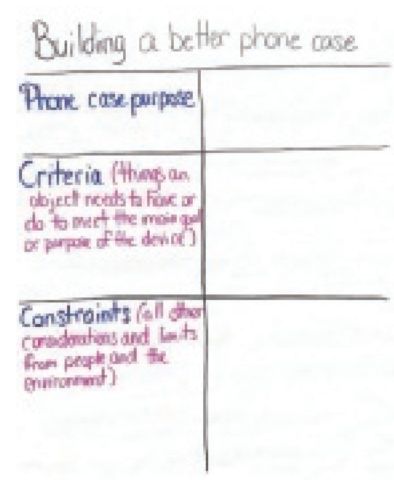
- Section off the chart into 3 rows with these labels at the left of the rows:
  - Phone case purpose
  - Criteria (the things an object needs to have or do to meet the main goal or purpose of the device)
  - Constraints (all other considerations and limits from people and the environment)

Create a chart titled "Objects Others Would Like to Protect from Damage".

Create a T-chart titled "Whole-class Criteria and Constraints" and with these column headings:

- "Criteria" on the left
- "Constraints" on the right





Create a T-chart titled “Objects that need (better) protection from a collision” and with these column headings:

- “Object” on the left
- “Idea to make it better protected from damage” on the right

Lesson 11 • Where We Are Going and NOT Going

Where We Are Going

In this lesson, students are tasked with drafting a design of a device to reduce damage for an object of their choice. Students will be asked to take into consideration why they are using certain materials and how those materials might reduce damage in a collision. Students will represent changes they believe are occurring to the protection device’s materials in a collision that will reduce the peak force on the object it is protecting. Students will also develop questions that they need to figure out regarding materials and device design (shapes and so forth) to best meet the criteria and constraints of the design.

Students are reminded in this lesson that in the *Homemade Heater Unit*, *Cup Design Unit*, and *Tsunami Unit*, they worked with criteria and constraints They recall examples of how they used these in the past to design and evaluate solutions for different stakeholders (entities like people, groups, or things that are impacted by design decisions).

Where We Are NOT Going

This lesson will not develop an explanation of why some materials are able to reduce peak forces on the objects they are protecting in a collision. At this point, the initial explanations are used to generate interest and competing ideas that will lead to the need in Lessons 12–14 for further investigation into how shape and material type influence the behavior of cushioning materials and how this affects peak force produced in a collision.

1. Revisit anchoring phenomenon.

10 MIN

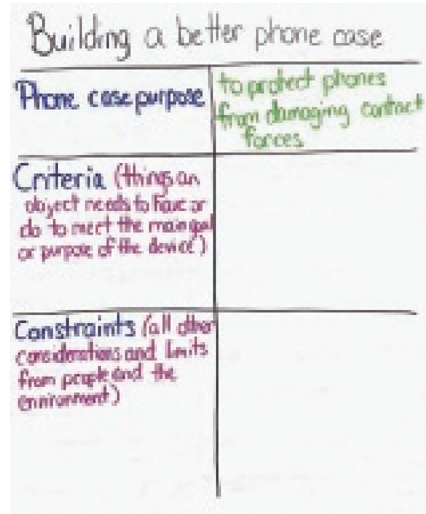
Materials: Building a Better Phone Case chart, markers

Recall anchoring phenomenon. Project **slide A**. Say, *When we started this unit, we looked at some interesting data. I was looking at it again and one piece of data stuck out. We've learned about and explained how different objects can get damaged in a collision, but even when some objects are protected sometimes they still get damaged. Look at these data from our original phenomenon.*

Read the data from slide A. Point out the datum regarding phones breaking while still in their cases.

- *27% of people said that their phone was in a case when they broke it.*

Say, *Even with cases, 27% of the phones were still getting broken! So the cases do not completely prevent damage.*



Establish the purpose of a phone case. Display the Building a Better Phone Case chart. Say, *If damage can still occur when a phone is in a case, why do people even use them? What would you think people would say is the primary purpose of a phone case?*

Students should respond that a phone case is meant to protect phones from damaging contact forces in many situations. Record this idea on the Building a Better Phone Case chart in the column to the right of "Phone Case Purpose". Say, *It seems like the phone cases, while helpful, are not fully protecting phones from damaging contact forces in every collision. What design features do we think would be needed to refine a phone case to better serve its purpose of protecting phones?*

Brainstorm phone case ideas. Ask students what potential design features a phone case needs that might offer better protection. Example responses are below.

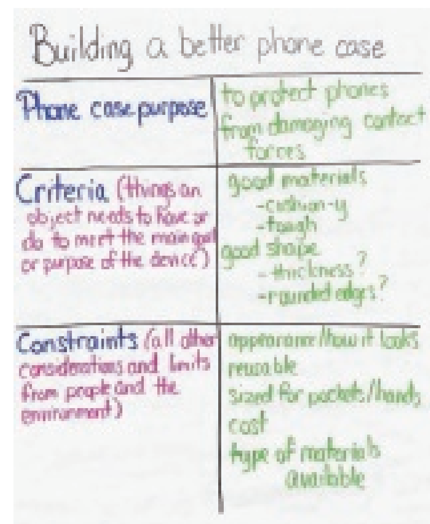
Suggested prompt	Sample student responses	Follow-up questions
Think about your phone cases. What could make that case better at meeting its purpose of protecting your phone?	*Maybe if there was something on the front to protect the screen.*	*Why might that be helpful? What would that do to help protect the phone during a collision?*
	If there's something there it might not hit it directly.	*So you're saying that maybe if we reduce the amount of direct contact with the phone, that may help make the case better?*

*** Attending to Equity**
Supporting Emerging Multilingual Learners: When revisiting vocabulary from past units, strategies that may benefit emerging multilingual learners are to use student-friendly definitions, make connections to cognate words when possible, and include a visual representation of the word. Adding the word to the Word Wall allows students to have a reference point for the meaning of the word, and by relating it to past experiences students can make connections across units to help develop the full meaning of the word, not just what the word means in one contextualized area or unit. Because these words were previously earned, meaning can be expanded upon as students engage in the engineering design process in a new context.

Suggested prompts	Sample student responses	Follow-up questions
What other things could make the case a better case?	*There could be, like, rounded bumpers on the corners. Last time I broke my case it landed on the corner.*	*Why might adding material or changing the shape be beneficial for phone protection?*
	Maybe more material helps protect it better.	*So you're saying increasing the thickness or changing the shape of materials seems to help reduce damage in a collision?*
Any other ideas that might make the case a better case?	*I think changing the type of materials, not just adding more, may make it a better case.*	*What changes to the materials are you thinking?*
	Some fragile things come in bubble wrap. Maybe we could use something like bubble wrap to protect the phones.	*So you're saying that the type of material used may help reduce damage in a collision?*

Shift focus to criteria and constraints. Transition to the "Criteria" and "Constraints" sections of the chart.

Project **slide B**. Say, *We have some ideas about what a phone case would need to better protect our phones. Let's create a list of the criteria and constraints a phone case designer would need to consider in making a better phone case.*



Remind students that in the *Homemade Heater Unit*, *Cup Design Unit*, and *Tsunami Unit*, we worked with criteria and constraints. In the *Cup Design Unit* students used criteria and constraints to design a new cup to keep a drink cool. In the *Tsunami Unit* students used criteria and constraints when evaluating different designs to protect communities from a tsunami. In the *Homemade Heater Unit* students used criteria and constraints to create a homemade heater for an MRE.

Criteria are the things a device needs to have or do to meet its main goal or purpose. *Constraints* are all other considerations and limits from people or the environment. Place the words *criteria* and *constraints* on the Word Wall for student reference. Remind students that we also worked together to define *stakeholders* in the *Homemade Heater Unit* and *Tsunami Unit*. *Stakeholders* are the entities like people, groups, or things that are impacted by design decisions. Add *stakeholders* to the Word Wall.*

Ask students the questions from slide B and have 2-3 students share out their ideas. Below are suggested prompts and sample student responses to the slide B questions. Fill in the rest of the Building a Better Phone Case chart as students share their criteria and constraint ideas.

Suggested prompts	Sample student responses	Follow-up questions
Let's look at row 2 on our chart. What criteria would a phone case need to have to better meet the purpose of protecting the phone?	*We need to use good, cushiony or tough materials that protect phones when they are hit.*	*So maybe we need to consider what materials work best for protecting a phone from contact forces?*
	We might need it to have rounded edges or thick sides, like thick and padded to protect the phone. The shape probably matters.	*So we want our device to have a good shape to help meet the goal of protection of our phones?*
Awesome. Let's think about the constraints. What are some stakeholder considerations we should have? Is there anything that would limit our designs?	*We would have to consider how it looks. We would want people to want to buy it.*	*So one constraint would be the appearance of the device?*
	It would have to work a lot of times, not just for one drop or impact.	*So you're saying that it needs to be reusable or sturdy?*
	We can't let it get too big. We need it to be comfortable to hold.	*We think one limit to the design might be size.*
	Money would definitely limit our designs. We don't have unlimited money.	*That's true. We would have to consider what people would spend on this. Cost will need to be on our constraints list.*
	We can't use just any material we want; we might not have access to some materials we may want to use.	*So we have to be realistic about the type of materials we have. We would have to use easy-to-find materials.*

Say, *It seems like we have identified some of the criteria and constraints a designer of a phone case should consider. But we all know phones aren't the only objects that people might want to protect from damage. Let's brainstorm some other possibilities. Is there anything other than a phone that you would like to better protect?*

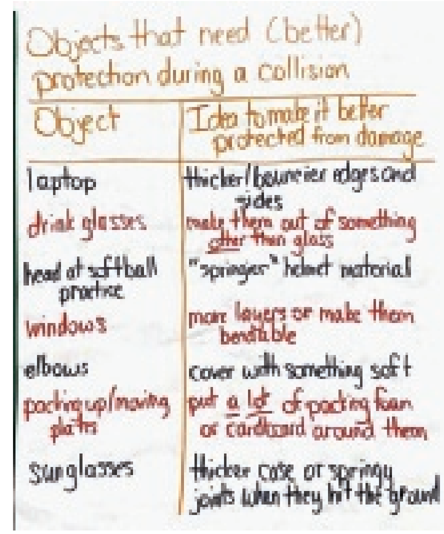
2. Chart other objects that need (better) protection. 6 MIN

Materials: Objects that need (better) protection during a collision chart, markers

Project **slide C**. Explain that the word *better* is in parentheses because some objects don't have protective devices. Other objects may already have protection devices, but they may need to be improved. Instruct students to turn and talk about the following questions.

- What are some objects that need (better) protection in a collision?
- What general ideas do you have to make it (better) protected from damage?

Make a record of better-protection design ideas. Project **slide D**. After about 4 minutes of student turn and talk, bring the class together to share their ideas. Ask students what objects they would want to protect or they think could be better protected. Display the Objects that need (better) protection during a collision chart. Create a record of the objects that need (better) protection in the left column of the chart. As students share, list in the right column one thing that would make the object more protected. If students suggest something that already has a protective device (such as a head in a helmet during a sporting event), ask them what would make the object better protected or make the existing protection device better.



3. Determine criteria and constraints of individual designs. **8 MIN**

Materials: *Protection Device Design Thinking*, Objects that need (better) protection during a collision chart, Building a Better Phone Case chart

Say, *We have a lot of objects that seem to need better protection, and we have a lot of ideas on how to make better protection devices.*

Turn and talk about potential protection devices. Project **slide E**. Reference the Objects that need (better) protection during a collision chart and point out the number of items that the class believes need (better) protection.

Direct students to turn and talk with their partner about the following prompts on **slide E**:

- If you had to pick only one object that you interact with a lot that you would want to protect from damage, what would you pick, and why?
- If we were to make a protection device for this object, what damage-reducing solutions could you come up with?

Pause students after roughly 2 minutes of partner sharing. Ask 2–3 students to share what object they would choose to protect and what solutions they would come up with.

Select an object to protect. Project **slide F**. Distribute *Protection Device Design Thinking*. Say, *It sounds like you all have great ideas. Let's see if we can draft some of these ideas on paper and think about how we can better protect our objects.*

Instruct students to write their name on the handout. Look at the first line with the students. Ask students to pick one object from the Objects that need (better) protection during a collision chart or choose an object that they would personally like to protect. Have students write this object down on the first line.

Look at the next part with students: "Define the purpose". Ask students to consider what the overall purpose of a protective device would be for an object. Give students time to write down the purpose of this protective device.*

Develop criteria and constraints for students' chosen object. Say, *As we work through developing a device that can better protect our objects, we have to think about what would make this protection device function better than any existing designs. We have to think about what we would need to do to meet the overall purpose of the design and any limits or additional considerations that stakeholders may want or need. Let's use the next three sections to help us determine our criteria and constraints.*

Make connections to the Building a Better Phone Case chart. Read over the last three sections with students. Point out that this is comparable to the ideas that we developed on our Building a Better Phone Case chart. Point out for students the "Criteria" and "Constraints" rows on the chart. Some students may point out that the overall

*** Supporting Students in Engaging in Asking Questions and Defining Problems**
Defining the design problem and identifying the goal or purpose of the design is central to the design work. The clearly defined design problem will help students better articulate the criteria and constraints needed to optimize the design and assess the effectiveness of any modifications to the device during the design process. The identification of goals also helps guide modifications to devices to better meet the stakeholder needs and design considerations.

goals or criteria are similar, if not the same, to the protection device they are wanting to design. If students make this observation, use this observation to navigate to the next section. If students do not make this observation, ask students if there are any similarities between the two lists and allow students to give 2–3 goals or criteria that are similar or the same.

Assessment Opportunity

Building towards: 11.A Define a problem that can be solved with the development of a protective device to reduce damage (peak force) during a collision by identifying and considering multiple criteria and constraints along with specific materials, shapes, and designs of devices that reflect our science ideas of how certain material properties function in a collision.

What to look for/listen for: On *Protection Device Design Thinking* students define the problem at the top of the page. Look for students to identify that the purpose of the device is for protecting the object from damage in a collision. Look for relevant criteria and constraints as students engage in the handout and listen for justification of the type of material and the shape of the materials they propose to use in their designs.

What to do: If students are struggling with identifying the purpose of the device, refer them to the Building a Better Phone Case chart. Ask students why they put a case on their phone and what that case is meant to do. While identifying criteria and constraints, have students think about the common example of the phone case once again. Criteria are directly related to the purpose. Ask students questions like these:

- What does this design need to have to serve the purpose of protection?
- What qualities would those designs have?
- What does the design need to do to serve its primary purpose?

For constraints, ask students to look back at the common example again for ideas. Ask questions like these:

- What are some things people would want out of this device that might affect how it functions?
- What else do we need to think about that the stakeholders want or need?
- Are there any restrictions due to the location where the object or design would be used?
- Are there any restrictions because of the way the object or design will be used?

As students consider different materials, refer them back to their previous work in Lessons 5–9 to help explain how objects behave in a collision.

Compare the chart with student handout answers. As students are thinking about their object that they would like to protect, have them compare their protection device with the Building a Better Phone Case chart.

Ask students these questions:

- Are there any criteria that would apply to your individual design AND to a better phone case?
- Are any constraints that also apply to both devices?

Have students consider the criteria and constraints that they will have to keep in mind while they are drafting their designs. Have students record these ideas in the last three sections on their handouts.

Ask 2–3 students to share what object they would like to better protect and what their criteria and constraints would be. Allow students to add to their lists as their classmates share their ideas for criteria and constraints.

4. Draft design ideas.

10 MIN

Materials: *Protection Device Design Thinking, Drafting Our Protection Device Design*

Give students time to draft their initial designs. Project **slide G**. Pass out *Drafting Our Protection Device Design* to students. Point out that column 1 is for an overview of their design. Students should draw what their design would look like, what materials they would use, and what shapes would be used in various locations such as corners and sides. Encourage students to use their design thinking from *Protection Device Design Thinking* to help them design a protective device. Point out that column 2 is space for a zoomed-in view of the main building materials in their device and that students should show what they picture the material(s) that make up their device doing a split second after something collided with it. Challenge students to really try to explain what the device is doing during the collision that enables it to reduce the peak forces on the object it is protecting in a collision.

Give students time to draft their ideas.*

Assessment Opportunity

Building towards: 11.B Design a solution to a problem to reduce the damage to an object in a collision (by reducing peak forces) by considering the properties of different, individual materials and shapes being used to serve particular functions.

What to look for/listen for: Treat this as a pre-assessment of students' understanding of new ideas that they will develop in the last lesson set of the unit. The first idea is related to the microscopic structure of cushioning materials. Many effective cushioning materials provide pockets or gaps of space or air between the layers of materials for the cushioner to "give". Look for this in the second column of the design drawing. The second idea is related to how cushioners reduce peak forces in a collision. Look for students showing the protection device deforming, based on the previous work in the unit. Students will likely not show the ideas listed below, as they are ones that are new to the remainder of the unit:

- The amount of peak force is reduced because the cushioner applies a weaker force over a larger distance in a collision, which has as much effect on reducing the kinetic energy of an object as a stronger force over a shorter distance.
- These forces are transferred to both objects that the cushioner is in contact with (including the object it is protecting).
- The shape of a cushioner can be designed to distribute that force over a greater surface area, thereby reducing the amount of peak force occurring at a single location on the object being protected.

What to do: *Drafting Our Protection Device Design* will reveal any preconceptions about how students believe forces on the protected object can be reduced by layering certain materials. Since these ideas will be introduced in the remainder of the unit there is no need for remediation at this point. Make a copy of these explanatory models at the

* Supporting Students in Developing and Using Structure and Function

Drafting Our Protection Device Design provides an opportunity to engage in both main elements of structure and function. Column 1 reflects student understanding of how particular structures can be utilized to serve certain purposes or functions based upon the science ideas learned thus far in the unit. Column 2 allows students to start thinking about how the structures (shape, material, and properties of these materials for the designed device) are affected and change over time as well as at a microscopic level during the collision. Students are likely to show the protection device deforming, based on the previous work in the unit, but may be less likely to show it transferring force to the object they are protecting in the collision.

end of day 2 and compare them with what students show in their individual model and explanation at the end of Lesson Set 3. You may also want to have students analyze their growth by comparing these artifacts related to the ideas listed above.

Circulate to clarify student thinking. As students are drafting ideas, circulate and ask students the following questions to clarify their thinking and refine their decisions.

- What shape are you using for your structure?
- What is special about that shape compared to other shapes?
- Would another shape work better or worse to help protect your object from damage? Why (or how)?
- What constraints did you identify? Do you think your device would meet those constraints? Do you have to consider sizing or type of material?
- What criteria did you identify? Can you explain on your handout how your device is able to meet those criteria?
- How do your main shape and materials help meet your criteria?
- What is special about the materials that helps protect against damage?
- How does that material react in a collision?
- What other materials would function like that material? What made you choose this specific one?
- How did you use those other ideas in your device design?
- Can you show and explain what sets your device apart from the other devices?

5. Receive feedback on designs.

11 MIN

Materials: *Drafting Our Protection Device Design*, 1 timer

Introduce a design feedback task and provide feedback. Project **slide H**. Explain that in order to make a better protection device, it can't be just what the designer of the device wants. It should meet the needs of many people who might want to use and buy it. Because of that, it is important to get feedback from others. Tell students that you will set a timer for 4 minutes. One student will explain their design to a partner, then their partner will have until the end of the 4 minutes to give feedback. When the 4-minute period has ended, the partners will shift roles. In the second 4-minute period the second person will explain their design and their partner will give feedback.

Instruct students to look at the questions on the slide. Read the feedback questions with students. Tell students to answer these questions as they give feedback to their partners.

- What do you like about the design?
- What changes would make it "better" at protecting the object?
- What other changes would you make for the device to be more appealing to stakeholders?

Allow students a total of 8 minutes to give and receive feedback with their partners, reminding students to shift roles after the first 4-minute timer goes off.

*** Attending to Equity**

Universal Design for Learning: Engineering design tasks are established with the purpose of meeting the goals of the design. The overall design of how the device meets those goals is directly impacted by the needs and considerations of the community (stakeholders). Taking home the student-created designs for additional feedback allows students to get more-relevant stakeholder input and *engage* with others in their community to understand how designs affect and are shaped by people involved. Additional stakeholder feedback will also contribute to the relevance and authenticity of the task to design a protective device for the object of the student's choice.

Additional Guidance

Questions are given for student feedback to help students focus on the protective qualities of the design while also allowing students to serve as the potential voice of a stakeholder. Structuring student feedback around focused questions helps students keep the feedback meaningful and connected to the overall science ideas of designing with stakeholders in mind and developing a device that has the primary purpose of protection.

Introduce home learning feedback task. Project **slide I**. Say, *We have received a lot of feedback on our designs! Tonight for home learning, see what your family and others think of your design. Take home your design tonight and revise it based on the feedback they give you.*

Have students ask others to give them feedback on their designs and list any other considerations family or others might want students to consider. Encourage students to write any feedback and considerations down in the margins or on the back of *Drafting Our Protection Device Design*. Tell them to be ready to share their feedback and ideas in the next class meeting and that they will be doing a gallery walk with their designs.*

End of day 1

6. Home Learning Feedback Gallery Walk

13 MIN

Materials: At least 3 3"x3" sticky notes for gallery walk feedback, *Drafting Our Protection Device Design*

Share home learning feedback. Project **slide J**. Have students get out their design ideas from the last class. Ask students to think about their home learning. Have students turn to a partner and share the feedback they received. If students did not receive feedback on their designs, have them consider their partner's feedback for their design and make any modifications they think are needed.

Bring students back together and ask students to place a checkmark or a star next to any changes they have made due to feedback from others.

Say, *How many of you feel that feedback from others helped make your initial design for a protective device better? Raise your hand if you received helpful feedback from someone else for your design.*

As several students raise their hand, say, *Great! It looks like we have gained some good ideas and feedback from others for our personal protective devices. It seems like the more specific the feedback, the better our modifications are. Let's take some time today and really focus on our feedback to make sure our designs are meeting the goals we identified.*

Introduce gallery walk questions. Project **slide K**. Tell students that in a moment we will have a gallery walk to give feedback on each other's designs. Explain that good feedback is specific and actionable, meaning that the feedback can be used to make something better, so they will be giving feedback over 3 important design questions. Go over feedback prompts with students.

- What changes would make it "better" at protecting the object?
- What other changes would you make about the way it looks, the material, or the shape that would make you (or others) more likely to want to use it more?
- What parts do you think will function well?

Present feedback structure. Tell students that they should give feedback on 3 different designs and use all 3 prompts during their feedback time. Students can give more than 3 pieces of feedback if they wish, but they should provide feedback on 3 different designs before coming back around to give more feedback. If they come to a design that has 3 sticky notes on it, they should try to find another design that has fewer than 3 sticky notes and leave feedback. No person can give more than one sticky note to a single design.

Provide time for a gallery walk. Arrange the design drafts for easy student access and viewing. Pass out at least 3 sticky notes to each student. Provide 6 minutes for students to give feedback on designs. At the end of the 6 minutes, have students return to their seats with their designs and read over their feedback.

7. Develop a shared criteria and constraints list. 8 MIN

Materials: *Drafting Our Protection Device Design*, partner feedback sticky notes, Building a Better Phone Case chart, Whole-class Criteria and Constraints chart, markers

Compare feedback. Project **slide L**. Instruct students to work with a partner to identify commonalities in their feedback. Students will use the following prompts to guide their conversations.

- What do your feedback and designs seem to have in common?
- Do your designs have similar criteria and constraints? If so, what are they?
- Do you have any feedback that is not similar to your partner's feedback?

Lead a criteria and constraints whole-class discussion. Project **slide M**. Bring students together and have them consider the criteria and constraints. Say, *Do we have a shared goal for all of our devices?* Students will identify that we all have the same shared goal of object protection.

Say, *Interesting. I wonder if we were to look at our criteria and constraints if they would also be similar across all protection devices. Let's see if we all seem to have common needs, limits, and considerations.*

Have students turn and talk about the following question:

- If we were to make a criteria and constraints list that would work for all our designs, what would be on the list?

Record class criteria and constraints. Display the Whole-class Criteria and Constraints T-chart. Use the same prompt from above to engage in a discussion about criteria and constraints that would be shared across designs. Start by pointing to the "Criteria" side first and asking students if they have a criterion that everyone might have on their designs. Students can reference *Protection Device Design Thinking* or *Drafting Our Protection Device Design* to look for criteria that others might also have listed or utilized. Repeat the same thing for constraints. Listen for these ideas and document them on the chart paper:

Criteria

- shapes that help to minimize damage (or prevent it completely)
- material(s) that helps to minimize damage (or prevent it completely)

Constraints

- time to build device

- money to build device
- availability of materials
- size
- limits to what we can actually construct as students
- looks good
- easy to use
- low cost to make
- good for the environment
- can be used more than once (reusable)

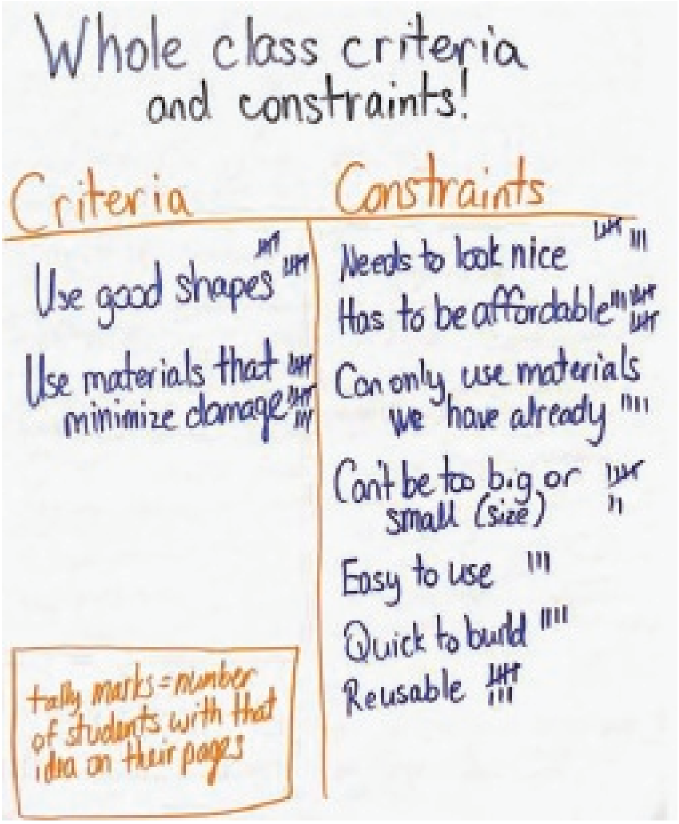
Additional Guidance

At a minimum, make sure that the ideas of shape, material, cost, availability of materials, and reusability are represented on the criteria and constraints consensus chart. The criteria of material type and shape will be revisited in Lessons 12–14. Cost, availability of materials, and reusability will be used by some students, depending on primary, secondary, and tertiary criteria feedback and use in Lessons 13–15. It is OK if more constraints present themselves during this list compilation, but the focus should be put on the ideas of material, shape, cost, reusability, and availability of materials as they are emphasized to drive future learning.

If multiple students feel an idea is important, place a star next to the idea or place tallies next to the idea to represent the number of students with that idea.

Discuss commonalities in charts. Instruct students to look at the Building a Better Phone Case chart and compare it to the Whole-class Criteria and Constraints chart that was just created. Ask students to share the similarities and differences of the charts. The criteria and purpose should be the same, and the constraints will have expanded sections on the new chart. Reiterate to students that the criteria are based upon the overall goals or purpose of the design, so it makes sense that the criteria are the same for all the different devices since they are serving the same purpose for a variety of objects.

Say, *We have a great list of criteria and constraints that we all agree would be helpful in designing our devices. But, this has me thinking about a lot of questions related to how we will design the best device we can to limit damage. What new questions does this raise for you about the materials, design, structure, and function of these devices? Let's write our questions down with possible ways to investigate them.*



8. Develop questions and ideas for investigations. 20 MIN

Materials: 3 more 3″x3″ sticky notes, *Protection Device Design Thinking*, *Drafting Our Protection Device Design*, partner feedback sticky notes, Objects that need (better) protection during a collision chart, Building a Better Phone Case chart, Whole-class Criteria and Constraints chart, chart paper, markers

Document questions and ideas for investigation. Project **slide N**. Arrange students in a Scientists Circle around a piece of chart paper. Pass out sticky notes to students. Ask students to look back at the class-created charts, their handouts, others' designs, and any feedback they received from others. Have students consider what questions they now have about the materials, design, structure, and function of the protection devices. Students will record on sticky notes at least 2 questions about materials, design, structure or function and record on at least 1 sticky note an idea for investigation. While students are recording their questions and ideas for investigation, set up a new T-chart on chart paper with the left side titled "What we need to figure out" and the right side "How we can investigate this."

Share questions and ideas for investigation. Project **slide O**. Review with students the expectations for sharing questions and ideas for investigation.

- One by one, we will go around and share one question and one idea for investigation.
- As the first person reads a question and an idea for investigation, give a thumbs up if you wrote down the same question or the same idea for investigation.
- The person reading the question and the idea will collect the sticky notes with the same question and the same idea for investigation from people with their thumbs up and will layer them on top of each other.
- The reader will then post them on our T-chart in the appropriate column.
- After this, the next person in the circle will read a question and an idea for investigation until all relevant questions and ideas are on the board.

Go around the circle and let students each read one question and one idea for investigation. Continue this until all questions and ideas are presented on the T-chart.

9. Navigation 4 MIN

Materials: None

Motivate the need for material testing. Say, *We have a lot of questions and ideas for investigations, and a lot of them seem to deal with our shared list of criteria and constraints.*

Project **slide P**. Ask students to turn and talk about the following question:

- If we are going to design a protection device, what is something that we all need to investigate to help us build a better device?

Elicit student responses. Use the prompts and responses below to guide navigation to the next lesson. It is OK if this discussion is continued at the beginning of Lesson 12 if time is short.

Suggested prompts	Sample student responses
If we are going to design a protection device, what is something that we all need to investigate to build a better device?	*Maybe look at criteria and constraints.*
So maybe we need to start with criteria to figure out how to protect our objects. What actually does the protecting of the object? What criteria do we need to figure out more about first?	*Maybe the materials?*
But how will we know what the best materials are to use? What would make one material better than another?	*The materials would have to protect better than another material. It would do a better job protecting the object.*
OK. But if we test the different materials, how will we know that one material is better at preventing or reducing the damage done on something it is protecting in a collision?	*We'd have to see which one produced less peak force on an object we're trying to protect.*
How could (or why would) measuring peak forces produced by different materials in a collision help us figure out which ones are more effective at preventing or reducing damage in a collision?	*The materials that produce less peak force in a collision should be more effective at preventing or reducing damage in a collision.*

Say, *As you leave class, start thinking about what we've done in the past and the equipment that we've used that we can repurpose to test different materials in a collision to see how they affect the peak forces in a collision. Getting some results for that next time will help us make informed decisions about one important criterion for determining which material types would work better for our designs.*

If desired, collect *Drafting Our Protection Device Design* as a pre-assessment of ideas developed in Lessons 12–15. Make copies of the handout and use the copies to compare to the students' individual models at the end of this lesson set. Return *Drafting Our Protection Device Design* to students at the beginning of Lesson 12.

SCIENCE LITERACY: READING COLLECTION 4

Materials, Design, and Outcomes

1. **Corked Baseball Bats**
2. **Criteria and Constraints**
3. **Plastics**
4. **Confessions of an Online Retailer**
5. **Protective Produce Packaging**

Literacy Objectives

- ✓ Summarize key points related to designing solutions to human problems.
- ✓ Organize related details about design criteria and constraints.
- ✓ Argue a position on the issue of using plastics for packaging.
- ✓ Contrast pros and cons of using plastic packaging.
- ✓ Translate text to visual/graphic representation of ideas.

Literacy Activities

- Read varied text selections related to the topics explored in Lessons 9–11.
- Evaluate the reading selections according to provided prompts and criteria.
- Integrate information gained from reading text with information gained from class investigation.
- Prepare a T-chart in response to the reading.

Instructional Resources

Student Reader

Collection 4

Science Literacy Student Reader, Collection 4
"Materials, Design, and Outcomes"

Exercise Page

EP 4

Science Literacy Exercise Page
EP 4

Prerequisite Investigations

Assign the Science Literacy reading and writing exercise *after* class completion of this lesson group:

- End of Lesson 9: How do other contact forces from interactions with the air and the track cause energy transfers in the launcher system?
- Lesson 10: Why do some objects break or not break in a collision?
- Lesson 11: What can we design to better protect objects in a collision?

Standards and Dimensions

NGSS

Disciplinary Core Ideas

ETS1.A: Defining and Delimiting Engineering Problems The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that is likely to limit possible solutions. (MS-ETS1-1)

PS2.A: Forces and Motion For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law). (MS-PS2-1)

Science and Engineering Practice: Asking Questions and Defining Problems

Crosscutting Concept: Structure and Function

CCSS

English Language Arts

RST.6-8.2: Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions.

RST.6-8.8: Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text.

RST.6-8.10: By the end of grade 8, read and comprehend science/technical texts in the grades 6-8 text complexity band independently and proficiently.

Core Vocabulary

Core Vocabulary: Core Vocabulary terms are those that students should learn to use accurately in discussion and in written responses. During facilitation of learning, expose students repeatedly to these terms. However, these terms are not intended for isolated drill or memorization.

constraint **criteria**

Language of Instruction: The Language of Instruction consists of additional terms, not considered a part of Core Vocabulary, that you should use when talking about any concepts in this exercise. Students will benefit from your modeling the use of these words without the expectation that students will use or explain the words themselves.

polymer **stakeholder**

A Glossary at the end of the Science Literacy Student Reader lists definitions for Core Vocabulary and selected Language of Instruction.

1. Plan ahead.

Determine your pacing to introduce the reading selections, check in with students on their progress, and discuss the reading content and writing exercise. If you are performing Science Literacy as a structured, weekly routine, you might implement a schedule like this:

- Monday: Designate a ten-minute period at the beginning of the week to introduce students to the assignment.
- Wednesday: Plan to touch base briefly with students in the middle of the week to answer questions about the reading, to clarify expectations about the writing exercise, and to help students stay on track.
- Friday: Set aside time at the end of the week to facilitate a discussion about the reading and the writing exercise.

Exercise Page

EP 4

2. Preview the assignment and set expectations.

- Let students know they will read independently and then complete a short writing assignment. The reading selection relates to topics they are presently exploring in their Contact Forces unit science investigations.
- The reading and writing will be completed outside of class (unless you have available class time to allocate).
- Preview the reading. Share a short summary of what students can expect.
    - *First, you will read a simulated sports magazine article that analyzes collisions in a baseball game and describes some ways professional players break the rules trying to hit the ball harder, faster, and farther.*
    - *Next, you'll read an article about how identifying criteria and constraints makes design problems more understandable and successful, whether you are a builder or coming up with a new way to get something done.*
    - *Then, you'll read a simulated popular science article about the advantages and disadvantages of using plastics.*
    - *You'll next read an online journal in which an imaginary baked goods CEO expresses her mixed feelings about using so much packaging.*
    - *Finally, you'll read a mock social media discussion of whether plastic cartons for apples are either too much packaging or just enough.*
- Distribute Exercise Page 4. Preview the writing exercise. Share a summary of what students will be expected to deliver. Emphasize that Science Literacy exercises are brief. The focus is on thoughtful quality of a small product, not on the assignment being big and complex.
    - *For this assignment you will be expected to generate a T-chart identifying the criteria and constraints for a new package solution for single apples.*
- Remind students of helpful strategies they can employ during independent reading. Offer the following advice:
    - *The reading should take approximately 30 minutes to complete.* (Encourage students to break reading into smaller sections over multiple short sittings if their attention wanders.)
    - *A good reading strategy is to scan through the collection first to see the titles, section headers, graphics, and images to see what the selections are going to be about before fully reading.*
    - *Next, "cold read" the selections without yet thinking about the writing assignment that will follow.*
    - *Then, carefully read the Exercise Page to understand the expectations for the writing part of the assignment.*
    - *Revisit the reading selections to complete the writing exercise.*
    - *Jot down any questions for the midweek progress check in class.* (Be sure students know, though, that they are not limited to that time to ask you for clarification or answers to questions.)

3. Touch base to provide clarification and address questions. (Wednesday)

Touch base midweek with students to make sure they are on track while working independently. You may choose to administer a midweek minute-quiz to give students a concrete reason not to postpone completing the reading until the last minute. Ask questions such as these, and have students jot answers on a half sheet of paper:

Suggested prompts	**Sample student responses**
How does replacing some of the wood in a baseball bat with cork give the batter an advantage?	*It reduces the mass of the bat, making it easier to swing the bat at a higher speed.*
Airbags deploy in collisions of eight miles per hour or higher. Is that a criterion or constraint of their design? Explain.	*It's a criterion because a government agency requires that all airbags be able to do this.*
What's a current problem with recycling plastics?	*In many places, there are no facilities that can recycle plastics properly, and it costs too much to transport the plastics to places where they can be recycled.*

Ask a few brief discussion questions related to the reading that will help students tie the text content to students' classroom investigations.

Suggested prompts	**Sample student responses**
How do lacrosse chest protectors and phone cases have similar criteria and constraints?	*Criterion: Both need to reduce damage during collisions.* *Constraints: Both need to be made of lightweight materials and conform to the shape of the person/phone they are protecting.*
What are some examples of collisions that a cookie-and-brownie business owner needs to consider?	*Cookies crumble and brownies break, so the owner has to figure out how to make sure that the products are transported in a way that reduces damage when the containers are stacked on each other, dropped accidentally on the ground, or tossed onto trucks.*
What kinds of collisions does the produce worker worry about when it comes to apples?	*stacking boxes containing apples and apples hitting other apples and bruising when the workers stack them in displays*

- Refer students to Exercise Page 4. Provide more specific guidance about expectations for students' deliverables due at the end of the week.
  - *The writing expectation for this assignment is to draw a T-chart identifying criteria and constraints for a design that keeps an apple fresh, unbruised, and delicious in your backpack for a few hours.*
  - *First, review the readings to make sure you understand the difference between criteria and constraints.*
  - *You'll also want to pay close attention to the readings about plastics and packing foods.*

Exercise Page

EP 4

- ◦ *Since the rubric says originality is important, your criteria and constraints should push the designer to come up with something different from what you have already seen.*
  - ◦ *Make sure that your criteria and constraints will all contribute toward meeting the goal you stated.*
- Explain that a well-organized T-chart should be easy to read and understand.
- Answer any questions students may have relative to the reading content or the exercise expectations.

4. Facilitate discussion.

(FRIDAY)

Facilitate class discussion about the reading collection and writing exercise. The first selection applies the concepts learned previously about collisions and forces to the specific examples about baseball.

Student Reader

Collection 4

Pages 34–43 **Suggested prompts**	**Sample student responses**
What is the general purpose of the first selection, "Corked Baseball Bats"?	*It describes all the different kinds of collisions that take place in a baseball game and some of the ways baseball players break the rules of the game, especially how and why they cork bats.*
What is the goal, or problem, that corked bats were designed to fulfill, or solve?	*The goal was to make changes to bats that would create more force when hitting a ball so that the ball would travel farther.*
What properties of cork were intended to improve batting performance?	*Cork is more elastic than the other woods used to make bats, and that was supposed to make the ball travel farther.* *Cork is also less dense than the other woods, and that makes the bat lighter and easier to swing fast.*
What is the general purpose of the second selection, "Criteria and Constraints"?	*It explains what criteria and constraints are and how stakeholders help identify them.*
How was this selection useful when you were getting ready to make your T-chart?	*The Vocabulary box gave dictionary definitions of these words that I could refer to as I was writing.* *The examples in the text helped me understand what the words mean.*
When you want to design something new, is it better to start by listing criteria or constraints?	*probably criteria because they tell you what the design should be able to do* *Either one could work, but you need to know both to get started.*

SUPPORT—If you are using the recommended word envelope convention, check the envelope to see if it contains any words, phrases, or sentences that students need help understanding. Read key sentences aloud, and provide concise explanation.

SUPPORT—Explain to English learners that *criteria* is a plural noun and that the singular form of this word is *criterion*. Point out that *criteria* is an example of an irregular plural noun because it was not formed by adding *-s* or *-es* to the singular form. Other examples of irregular plurals are *knives* (*knife*), *feet* (*foot*), and *mice* (*mouse*).

Pages 34–43 **Suggested prompts**	**Sample student responses**
Who would the stakeholders be for a new design for carrying apples in backpacks?	*students who would carry them, parents who would pay for them, and the people who could make money selling the new design*
What is the general purpose of the third article, "Plastics"?	*It explains why plastics are useful, where they come from, and what happens to them when people are finished using them.*
What properties of plastics make them useful in reducing the forces of collisions in many situations?	*They are lightweight but strong, waterproof, easily shaped, and long-lasting.*
What criteria would you include for a newly designed plastics recycling system?	*that all the different kinds of plastics be recycled there* *that the facility be small and located near the sources of plastics*
What is the general purpose of the fourth article, "Confessions of an Online Retailer"?	*It debates the pros and cons of various packaging materials used by a baker to ship her products.*
Cornstarch packing peanuts are better for the environment but are more expensive to produce than plastic packing peanuts. How could talking to stakeholders help the bakery owner use them more frequently?	*The owner could ask customers if they would like to pay a little more to share the cost of environmentally friendly packing materials.* *Maybe the owner can sell cookie crumbs as a new product for people to sprinkle on yogurt or ice cream. This product might need less packaging.*
What ideas from this reading could you use for your writing task to list criteria and constraints for a product that will protect apples?	*I thought about whether the design should use bubble wrap or packing peanuts to cushion the apple.* *It also made me think about the cost of the materials.*
What is the general purpose of the fifth article, "Protective Produce Packaging"?	*At first, the social media poster wanted to persuade her online community that plastic crates for apples are silly. But then she reported points made by the store worker about how plastic crates might be less wasteful than she thought.*
How does the fifth selection help you build knowledge on top of what you learned in the fourth selection?	*The fourth article shows that business owners worry about how the products they make are transported. The fifth article shows how the customers are also concerned.*
How did this reading help you get ready to develop your T-chart?	*I used the plastic crate idea shown in the photo to spark ideas about how to protect the apple inside my backpack. I also thought about the environmental impact of the materials I could use in the design.*

CHALLENGE—Some students may be ready to do independent research on polymers. Have them use reputable science websites to define *polymers*, describe their molecular structure, and explain what happens to them as they age.

5. Check for understanding.

Evaluate and Provide Feedback

For Exercise 4, students should copy the template provided to develop a T-chart listing criteria and constraints for designs that can solve the problem of keeping an apple fresh and unbruised while carried for hours in a school backpack. Look for evidence that students can state the problem as a goal, that they can distinguish criteria from constraints, and that they have built on the information in the readings.

Use the rubric provided on the Exercise Page to supply feedback to each student.

LESSON 12

What materials best reduce the peak forces in a collision?

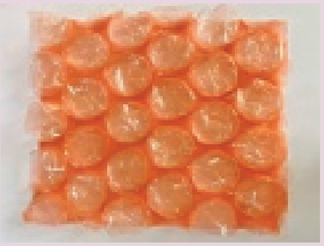
Previous Lesson

We revisited our anchoring phenomenon and discovered that some phones were in cases when they were damaged. We developed new phone case criteria and constraints and designed a protection device for something new. We received design feedback and developed an encompassing set of criteria and constraints.

This Lesson

Investigation

2 DAYS



We conduct an investigation to determine what easily accessible materials reduce peak force in a collision. We compare the structure of the materials and find similarities in their compositions that might affect their function. We also determine that the peak force is reduced equally on both objects, regardless of size. We try to develop a model to explain how the structures of the materials function in a collision that helps to reduce peak forces on the objects we want to protect.

Next Lesson

We will develop a model to represent how the structures of materials compare in the top four performers for peak force reduction. We will use scaled-up versions of these structures to generate data using slow-motion video about the unobservable mechanisms at work in the system. We will carry out an investigation to determine how the amount of force applied to different points of a cushioning structure is affected by the shape of that structure.

Building Toward NGSS

MS-PS2-1, MS-PS2-2, MS-PS3-1, MS-ETS1-2, MS-ETS1-3, MS-LS1-8

What Students Will Do

12.A Analyze data to determine which materials reduce peak force in a collision and analyze the similarities (visual patterns across materials) in the properties of those materials (macroscopic deformability).

12.B Develop a model to explain how the changes in the structures of cushioning materials contribute to their function (a reduction in peak forces) at a microscopic level during a collision.

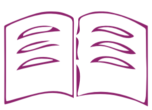
What Students Will Figure Out

- Materials that reduce peak force have similar structures, such as air pockets or space for air, and the ability to deform when a contact force is applied; these materials reduce the peak force equally on both objects involved in the collision.

Lesson 12 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	4 min	**NAVIGATION** Review the previous lesson and determine the basic materials testing setup.	A-B	
2	10 min	**INTRODUCE MATERIALS AND MAKE PREDICTIONS** Create a chart of potential protective materials in science notebooks and predict the effect of different materials on peak forces. Share ideas by taking a class poll.	C-E	*Material Charts* (optional), 1 set of each of the prepared test materials, cotton balls, balsa wood, foam earplugs, styrofoam, cardboard, metal, CD case, large bubble wrap, small bubble wrap, fabric
3	12 min	**DETERMINE BASELINE PEAK FORCE AND DELEGATE TESTING OF MATERIALS** Demonstrate the setup for measuring peak force reduction and take a baseline without any potential reduction materials in the system.	F	Materials Testing Lab
4	18 min	**CONDUCT MATERIALS TESTING**	G-I	Materials Testing Lab *End of day 1*
5	6 min	**COMPARE CLASS DATA** Compare class data for various materials and make initial claims about materials.	J	
6	4 min	**REVIEW DATA AS A CLASS** Look at materials data as a class and determine which materials reduced peak forces best.	K	*Up Close Images*, Force Reduction Chart
7	8 min	**COMPARE FORCES ON BOTH OBJECTS WITH PROTECTIVE MATERIALS** Use different spring scales with and without force-reducing materials to determine that the peak forces on each object are equal with and without protective material.	L-M	1 5-N spring scale, 1 10-N spring scale, 1 force-reducing material from Materials Testing Lab
8	8 min	**COMPARE MATERIALS AND EXPLAIN MATERIAL STRUCTURE** Look at different peak-force-reducing materials and compare their structures. Develop an initial explanation of how the materials help to reduce peak force when a contact force is applied.	N-O	*How do we sense different textures?* (optional), *Up Close Images*
9	14 min	**CONSTRUCT INDIVIDUAL MATERIAL EXPLANATIONS** Use bubble wrap and cotton balls to develop an explanation of how the properties of the protective materials behave to reduce the amount of peak force when a contact force is applied.	P	1 1”-square piece of small bubble wrap, 1 cotton ball, *How can materials reduce peak force on the objects they protect?* *End of day 2*

Lesson 12 • Materials List

	per student	per group	per class
Materials Testing Lab materials	• safety goggles	• 2 5-N spring scales attached to 2 carts with hook and loop fasteners with a twist tie force collar on one spring scale plunger • 2 electrical plates • 1 vinyl flooring strip • textbooks or binders to lift track 8″-12″ • 2 of the same test material (type of material will vary per group) • 1 aluminum track • 1 brick • 2 pieces of sticky tack • 1 container of clay • 1 ruler or measuring tape • transparent tape • 1 strip of duct tape • *Cushioning Materials Testing Procedures*	• Force Reduction Chart • digital scale • 2 5-N spring scales attached to 2 carts with hook and loop fasteners with a twist tie force collar on one spring scale plunger • 2 electrical plates • 1 vinyl flooring strip • textbooks or binders to lift track 8″-12″ • 2 of the same test material • 1 aluminum track • 1 brick • 2 pieces of sticky tack • 1 container of clay • 1 ruler or measuring tape • transparent tape • markers
Lesson materials **Student Procedure Guide**  **Student Work Pages** 	• science notebook • *Material Charts* (optional) • *Up Close Images* • *How do we sense different textures?* (optional) • 1 1″-square piece of small bubble wrap • 1 cotton ball • *How can materials reduce peak force on the objects they protect?*	• 1 5-N spring scale • 1 10-N spring scale • 1 force-reducing material from Materials Testing Lab • *Up Close Images*	• 1 set of each of the prepared test materials • cotton balls • balsa wood • foam earplugs • styrofoam • cardboard • metal • CD case • large bubble wrap • small bubble wrap • fabric • Force Reduction Chart

Materials preparation (25 minutes)

Online Resources

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Day 1

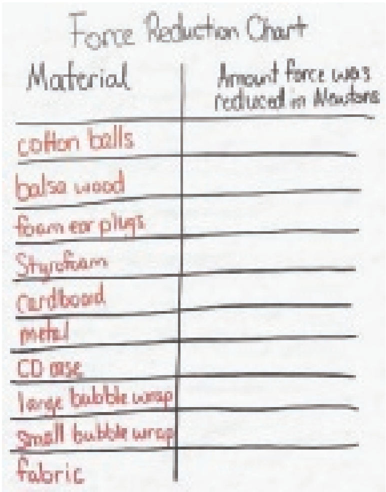
- Consider printing a chart for each student from *Material Charts*. Cut into individual charts for student use. Students can also draw this chart in their notebooks. Students with writing difficulties or accommodations could benefit from a copy, which would reduce the amount of writing.
- At the end of the day, collect and reserve the test materials to have on hand for day 2.

Day 2

- Cut a small piece of small bubble wrap (roughly 1" x 1") for every student.
    - Decide if students will be allowed to pop the piece of bubble wrap after completion of their model.
    - If students are allowed to pop the bubble wrap, cut enough wrap for every student in every class.
    - Make a plan for collecting bubble wrap (used or unused) after the activity. Depending on the material, some types of bubble wrap can be recycled. Check for the recycling symbol on the bubble wrap packaging.
- Have large cotton balls available for all students (one per student).
    - Make a plan for collecting cotton balls after the activity.
- Have all spring scales available for partner pair use.
- Have available the reserved testing materials (1 material per partner pair).
- Make enough copies of *How can materials reduce peak force on the objects they protect?* for all students.

Day 1: Materials Testing Lab

- **Group size:** 3-4 students
- **Setup**
    - Determine a way to allocate different testing materials to student groups. Some ways include pulling sticks, counting off 1 through 10, and drawing a number out of a bucket.
    - Create the Force Reduction Chart.
    - Watch video to set up a teacher demonstration station. (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)
    - Set up collision carts demonstration (see *Setup for Collision Carts Demonstration* for images of these steps):
        - Add textbooks or binders to elevate one end of the flooring strip 8"-12" to create a ramp.
        - Angle the lower end of the vinyl flooring strip into the brick.
        - Place the metal track on the vinyl flooring strip and with its lower end against the brick.
        - Place the push-pull spring scales on the carts using the hook and loop fasteners.
        - Mount a plastic, blank electrical plate on the end of the rod on each of the 2 push-pull spring scales using sticky tack.



    - Make sure that the two electrical plates touch flush when the carts are pushed together.
    - Using duct tape, tape down one cart at the bottom of the ramp about 4 inches away from the brick with its plate facing up the ramp.
- Prepare materials for student use.
    - Gather testing materials for each class:
        - 8 large cotton balls
        - 2 balsa wood slices
        - 8 foam earplugs
        - 2 4″ x 2.5″ pieces of Styrofoam
        - 2 4″ x 2.5″ pieces of cardboard
        - 2 quarters or other flat pieces of metal objects such as washers
        - flat plastic of CD case
        - 2 4″ x 2.5″ pieces of large bubble wrap
        - 2 4″ x 2.5″ pieces of small bubble wrap
        - 2 4″ x 2.5″ pieces of terry cloth fabric
    - Larger testing materials listed above (bubble wrap, balsa wood, cardboard, CD case pieces, fabric, Styrofoam) should be cut to a size that allows for the materials to easily fit onto the front of the electrical plates (roughly 4″ x 2.5″). If the balsa wood comes in a smaller size, it will still function correctly as long as the wood is lined up well with the opposite piece of balsa wood on the opposing electrical plate.
    - The CD case will need to be taken apart. It may be easier for students to use the CD case front on one electrical plate and the CD case back on the opposing electrical plate. This is fine as long as the plate does not drag on the aluminum track.
- Prepare student lab stations per group:
    - Print 1 copy of *Cushioning Materials Testing Procedures* per group. A color copy can also be found in the *Student Procedures*.
    - Provide the following materials for every student station.
        - 8″ of transparent tape
        - 1 12″ strip of duct tape
        - 2 blank electrical plates
        - 2 pieces of sticky tack (can already be attached to plungers)
        - 1 piece of vinyl flooring
        - textbooks or binders to elevate ramp (Keep the height consistent across groups to help account for drop angle.)
        - 1 piece of aluminum track
        - 2 5-N spring scales attached to 2 carts with hook and loop fasteners with a twist tie force collar on one spring scale's plunger

- ◦ 1 container of clay
  - ◦ test materials
- **Notes for during the lab**
  - While students are engaging in the lab, circulate to make sure the twist tie force collar is getting reset in between each trial.
  - Check that students are consistently measuring the force from the same side of the twist tie force collar (front or back).
  - Make sure that students are pulling back the moving cart to the same spot consistently each trial.
- **Safety**
  - Wear safety goggles or glasses during the setup, hands-on, and take-down segments of the activity.
  - Carts can fall off the tables if a brick is not placed at the end of the track. Make sure each station has a brick at the end of the track.
  - Bricks are heavy and can cause injury when dropped on body parts. Make sure all bricks are away from edges of tables or areas where there is a drop risk.
  - Make sure all fragile items are removed from the test area.
  - Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
  - Immediately pick up any items dropped on the floor so they do not become a slip or fall hazard.
- **Storage**
  - ◦ All materials from this lab can be stored and reused indefinitely.

Lesson 12 • Where We Are Going and NOT Going

Where We Are Going

Students will compare the data gathered from the testing of multiple materials to analyze similarities and differences in the peak force reduction of different materials. Students will compare the microscopic structures of those materials to determine what properties of the materials might contribute to peak force reduction when a contact force is applied.

Where We Are NOT Going

While students may be identifying or be assessed on similar properties of force-reducing materials, students will not be altering their designs with new findings until a later lesson. Students will also not be making a conclusion that one protective material is definitively better than another. In the next lesson students will be weighing other criteria and constraints against the materials to learn that each material has a trade-off. Students will not be coming to consensus about the molecular-level interactions that lead to a greater force reduction in this lesson. The data collection will be limited to forces parallel to the surface of the track. This is treated as a set of horizontal interactions between the push-pull spring scales and cushioning material, even though the track is slightly tilted. The vertical forces in the system (e.g., gravity) and forces perpendicular to the track surface (e.g., normal forces) will not be discussed.

1. Navigation

4 MIN

Materials: None

Recall criteria for our protective device from the previous lesson. Project **slide A**. Say, *Let's look back at our criteria list from last time. We know that in order to have an effective protection device design we need to meet our criteria. One criterion we identified was using materials that will protect our object. What does that mean?*

Suggested prompts	Sample student responses
What does it mean to use good materials that are protective? What would those materials do?	*It means the materials reduce peak force on the object in the design.* *The materials are designed to protect objects.*
How do you think those materials function?	*Maybe the materials move more before they reach their elastic limit.* *The materials might squish.*
How do we think those materials help reduce peak force in a collision?	*The materials might absorb some of the energy being transferred to or through it.* *Maybe they give or deform more easily.*

Say, *It sounds like we have some varied ideas on what exactly it means to have a protective material and what that material does to help reduce the peak forces in a collision. We need to figure out which materials would best fit the goal of protection for our objects. Turn and talk with a partner about other things we have done to measure peak force that we might be able to reuse today.*

Share protective material ideas. Project **slide B.** Give students a moment to turn and talk. Once students have had a chance to talk with a partner, bring the class together and have students share their ideas. Example prompts and responses are below.

Suggested prompts	Sample student responses
How have we measured peak force in the past that we could reuse or repurpose for our investigation today?	*We had a lesson where we used peak force collars on spring scales to see the amount of peak force in a collision.*
How can we use that to test different materials' peak force on objects in a collision?	*We'd have to use the same setup and add the materials to it.*
So if we add our protective materials in front of the object we are protecting and then collide a moving object into it, we could see if the peak forces were reduced?	*Yeah.*
Great! It sounds like we have a general plan to test our materials.	

Additional Guidance

If students have trouble coming up with the idea of using the peak force collar on a spring scale, direct students to look back in their Progress Trackers for a time when we were learning about peak force. Ask them what investigation was done to learn about peak force and what materials were used. Guide students to the idea of using the same setup that was used in a previous test, but adding in the potential protective materials that we want to use in the collision-cart interaction.

2. Introduce materials and make predictions.

10 MIN

Materials: science notebook, *Material Charts* (optional), 1 set of each of the prepared test materials, cotton balls, balsa wood, foam earplugs, styrofoam, cardboard, metal, CD case, large bubble wrap, small bubble wrap, fabric

Tell students that after looking at their designs from the gallery walk in the last class and seeing the materials they used, you were able to find certain comparable materials around the classroom for them to test.

Make protective material predictions. Project **slide C**. Show students each material. Either pass out to each student a copy of the materials chart from *Material Charts* or have students create in their notebooks the chart from **slide C**.* Ask students to make predictions about which materials will better reduce peak forces in a collision. Students will add the following markings in the second column on their charts to indicate their predictions:

- + if the material will increase peak forces during a collision
- - if the material will reduce peak forces during a collision
- = if the peak forces will remain the same during a collision

Ask students to look at the materials for which they marked a minus. Have students circle a material with a minus that they think will do the best job of reducing peak forces in a collision.

Share ideas with a partner. Project **slide D**. Once students have had a chance to make predictions about materials, have them turn and talk with a partner about their predictions. Have students use the following questions to guide their partner discussion:

- What material do you think will **reduce** peak force the most? Why?
- What material(s) do you think will perform the **worst**? Why?

Take a class poll over materials ideas. Project **slide E**. Bring students together and have them share their ideas on the best and worst performers by taking a class poll for each. For the first poll, read out loud each material listed in the chart, pausing after every one. Have students raise their hand if they think the material will be the best performer. If any material has several hands raised, ask students why they think that the material would be the best at reducing peak forces. Continue the process of reading the materials, taking a poll, and asking students their reasoning until all materials have been read.

Take a second poll. Ask students which materials would do the worst at reducing peak forces. Explain to students that this could mean that they are reducing the forces very little or not at all or even increasing the forces. Read through the list of potential protective materials again, pausing after each one to take a poll, and, for materials that have several hands raised, asking students why they think that particular material would do the worst at reducing peak forces. Accept all answers. Keep going until all materials on the list are read.

*** Attending to Equity**
Universal Design for Learning: *Material Charts* is provided as a scaffold to save time from students having to copy the chart from the slide. In addition, it can be used as a support for students who struggle with copying from a slide into their notebook with enough room to record data to be able to *engage* with the activity.

Additional Guidance

Universal Design for Learning: Taking a poll allows for students to *engage* in presenting their ideas in a low-risk manner. Students can share their ideas without being pressed to go public individually and/or to explain their predictions without specific evidence to cite. By asking the entire group about the identification of certain materials falling into the categories of being best or worst performers, not just the students who have their hand raised, students feel less pressured to make a prediction about a material as their classmates can chime in and give their perspective on the polling choice.

Say, *Interesting. It seems that we have different ideas on which materials would be best to use in our designs and even which materials we would want to avoid for protective purposes in our designs. We also have some ideas about why those materials might work or not work, but we aren't sure. We'll need to collect some data to see which of our predictions are supported and which are refuted by the evidence.*

3. Determine baseline peak force and delegate testing of materials. 12 MIN

Materials: Materials Testing Lab

Determine materials lab setup. Project **slide F**. Show students the basic setup at the demonstration table. Draw attention to the peak force collar that was used in Lesson 5. Ask students the following prompts:

- *We want to see if our materials reduce the peak force in a collision.*
  - *Where would we have to place the material so that we could see if it reduces the peak forces on our colliding objects?*
  - *How can we secure the test materials in place when we are running our tests?*

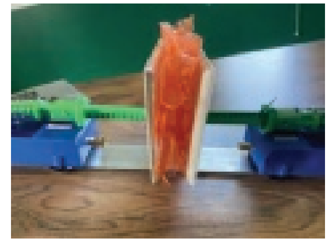
Discuss the two questions as a whole group. Students should determine that the potential protective material should be placed in the middle of the collision, in between the two objects that are colliding.

Arrange students around the demonstration table. Explain to students that some materials will not fit onto the plungers, so we will be adding an electrical plate to the front of each cart using sticky tack.

Show students how to tape the potential protective material on the electrical plates by creating a tape circle with the sticky side facing outward.

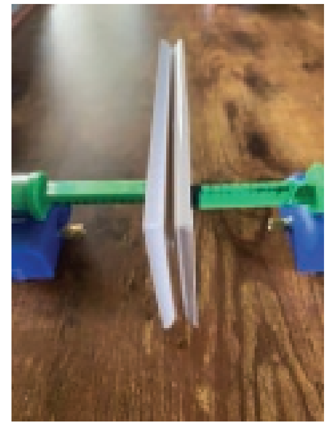
*** Supporting Students in Engaging in Planning and Carrying Out Investigations**
In the next step, students will receive *Cushioning Materials Testing Procedures*. While students are checking their data for variances after their materials testing, they may find that there are variances larger than the allowable amount and that do not meet the goals of the investigation. From this point, students will have to assess what potential revisions were imparted on the experimental design for the variance in data and then revise their data collection method to better align with the class data collection protocol for this lab.

Attach a material to the front of both electrical plates and show how they line up when the two carts come into contact. Explain that as long as the materials are in the middle of the collision, it should give the data we need.



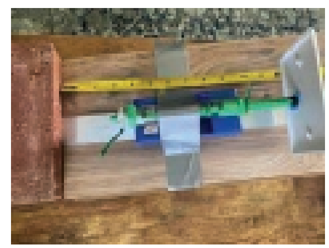
Explain material setup.

Remove the protective material from the front of the electrical plates. Demonstrate for students how to set up the spring scale setup (see video in the Lab Preparation section), making sure to point out again how to adjust the electrical plates so they are flush with each other at contact. By removing the padding at this moment, students can see how well the blank electrical plates line up without the visual interference of the protective materials.



Review force collar use.

Review that this force collar setup will allow us to observe the peak amount of force on our carts during the collisions. Using duct tape, secure the nonmoving cart 4 inches away from the brick.



Draw attention to the force collar. Show students that the force collar is on the “0” mark on the nonmoving cart.

*** Attending to Equity**

Universal Design for Learning: Some students may be able to physically manipulate materials better than others due to motor skill differences. When assigning materials, it may be helpful to keep in mind the effort it takes to attach the materials to the carts. It also might be helpful to have ready-made tape loops for students to use. If something other than transparent tape is used, make sure that it is very lightweight so that the mass is not affected from cart to cart.

Easy-to-attach items

- cotton cloth
- balsa wood
- cardboard
- small bubble wrap

Harder-to-attach items

- cotton balls
- earplugs
- metal
- CD case plastic
- large bubble wrap

Place the moving cart at the top of the ramp. Release the moving cart towards the nonmoving cart. After the collision, observe where the force collar rests on the nonmoving cart. Point out to students the new location of the force collar and review how to read the measurement consistently at the back of the twist tie. Remind students that each mark represents 1/10 of a newton.

Additional Guidance

Students may ask why we are using the ramps rather than the spring-scale launchers for this investigation. If they do, you can say the spring-scale launchers provide a way to ensure that we are doubling the speed of a cart launch by pulling back the plunger twice as far, but they tend to have more variability in their results because of how hard it is to make sure we are pulling back the plunger to exactly the same point on the plunger in repeated trials. But the ramp is easier to ensure that we pull the cart back to the same point on the ramp each time, though it is less useful for doing experiments where we want to double the speed of the launch, which is not the goal of this investigation.

Create the need for multiple trials. Now that students have had a chance to view the setup, say, *Let's do this demonstration one more time to make sure we know how it works.*

Intentionally lift the cart to a slightly different height on the track and release the cart. Have a student read where the force collar rests. Point out that it is at a slightly different spot.

Ask students:

- *Will we always get the exact same results?*

Students should respond that it depends on the trial and that small differences can occur. Ask students what we can do to account for these small differences. Elicit the idea that we can take an average of the data to account for small differences in how we release the cart and other variables that are hard to control.

Controlling for other factors. Explain that we will also have to keep track of the mass of our carts. As we figured out in Lesson 5, the mass affects the amount of kinetic energy an object has, which in turn affects the peak force. Because of this we will use a digital scale to make sure all carts weigh exactly 200 g. Show students how to add clay to the cart cavities on top to adjust the weight of the cart to 200 g.

Run the demonstration at least 2 more times to demonstrate to students how to check for semi-consistent results. Explain to students to look at their data once they are finished. If there is a larger variance than +/- 0.2 N from the mode of their measurement, check that the collar isn't loose and rerun that trial.*

Introduce Force Reduction Chart. Post the Force Reduction Chart in an easily accessible part of the room for students. Explain to students that they will be splitting up to test different materials listed on the chart. These materials are readily available, and while they may not reflect all materials they are wanting to use in their design, the materials we have to test have very similar features.

Assign groups and distribute test materials. Divide the class up into groups to test the materials. Label the materials 1-10. Randomly assign the materials to groups using the method determined in the Lab Preparation section of the *Teacher Guide*, such as choosing sticks, counting off by 10, and so forth. Have a student from each group collect the testing materials for their group. Explain that they will not be given extra materials, so they should use the materials carefully. Bubble wrap and other materials should not be popped or destroyed.

4. Conduct materials testing.

18 MIN

Materials: Materials Testing Lab

Calibrate group devices. Project **slide G**. Direct students to set up the spring scale, cart, track, flooring strip, books, and brick in the same arrangement as the teacher demonstration setup. Distribute a piece of duct tape to every group for students to secure the nonmoving cart. Instruct students to follow the directions on the slide to calibrate their spring scales. Explain that it is important to calibrate the spring scales first so we can accurately compare the potential force reduction data from our materials testing.

- Check your spring scales. Do they show 0 newtons when held horizontally?
- Push in and out on the spring scale rod a couple of times and make sure that it rests at 0 newtons.
- If it is not at 0, use the white screw on the end to adjust the scale. Once you have it set, push in on the rod and let go to check that it rests at 0 newtons.

Distribute testing procedures. Project **slide H**. Distribute *Cushioning Materials Testing Procedures* to students. Read through the directions with students and have them highlight or star the places where they will stop and record their data. Point out the differences between the two data tables and explain how to use the subtraction table located in the final section to help students find the difference in peak forces during the collisions.

Conduct materials tests. Display **slide I**. Once it has been verified that all the devices are calibrated, have students run 6 tests without the protective material in the system and record the data for each trial on their handout. Students will need to establish a baseline, or control, for their readings to determine if the protective materials actually reduce peak force on their objects.* Explain that there are variables that we cannot control for in the way we set up our work stations (e.g., some wheels may be slicker than others, some peak force collars may be slightly tighter than others), but by comparing the peak forces of the control and the experimental trials at each station, we will get a better picture of the overall peak force reduction potential of the materials.

Remind students to use tape, not sticky tack, during the second part of the investigation to add their material on the carts' electrical plates. Make sure students keep the test materials in line with the plunger as much as possible. Students will run each test 6 times, then average their data.

Additional Guidance

During this investigation students work in small groups to run and record data for multiple trials and calculate the averages in the data for a control condition and for an experimental condition with one cushioner on *Cushioning Materials Testing Procedures*. Students use these data to determine the average amount of force reduction in their cushioner. As students are working, circulate and assist students. Make sure students are

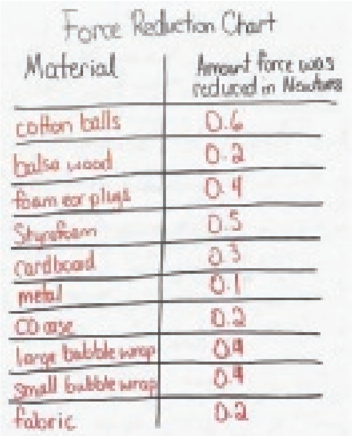
*** Supporting Students in Engaging in Planning and Carrying Out Investigations**
Over the course of the units students develop their skill of planning and carrying out investigations. Here, the idea of establishing a baseline as a control condition is discussed with students. The data from each trial or setup might be slightly different based upon slight, uncontrollable changes to the cart, positioning, and so forth, but the overall change to the peak forces in the system can be compared from one protective material to the next. While we cannot control for everything in the system, the peak force comparisons of the control to the experimental trials will allow for better comparison of all the protective materials.

*** Supporting Students in Engaging in Planning and Carrying Out Investigations**
Testing specific materials leads to an understanding of which types of materials help to reduce peak forces in a collision. The testing of

- recording multiple trials,
- calculating averages for both the control and the experimental condition, and
- calculating the difference between the control and the experimental conditions.

If the data seem skewed, have students look back at the raw trial data from the lab. If students find more than 0.2 N variance from the mode of their measurement, they should be encouraged to check that the collar isn't loose and re-run that trial.

After data collection is completed, students will then find the difference between the control peak force average and their materials test peak force average and add it to the class chart. These data will be reviewed individually and as a class during the next class period and should be checked as students are recording their data. Once students are finished adding their data to the class chart, have students dismantle their lab setup, put away materials, and return the protective materials for use in the next class period. Here is an example of a completed class chart.


Force Reduction Chart

Material	Amount force was reduced in Newtons
cotton balls	0.6
balsa wood	0.2
foam ear plugs	0.4
Styrofoam	0.5
cardboard	0.3
metal	0.1
CD case	0.2
large bubble wrap	0.4
small bubble wrap	0.4
fabric	0.2

materials provides evidence that will serve to better refine design solutions. By understanding which materials work better to reduce peak forces, students can make an informed decision to modify devices to better meet their criteria and constraints, which will be built upon in Lesson 14.

Additional Guidance

In the next class period, students will look for consensus on identifying the top 3 to 5 materials that seemed to work best to reduce peak force.

These materials should include

- one or both types of bubble wrap
- foam earplugs
- Styrofoam
- cotton balls

If at least three of the top performers listed above don't appear in a class set of data at the end of day 1, have that class compare their data to another class's data at the start of day 2. Emphasize that more data can make us more certain and have students look for patterns across class data sets (e.g., which materials are in the top five performers in the most classes).

End of day 1

5. Compare class data.

6 MIN

Materials: science notebook

Individually reflect on results. Display **slide J**. Have students look back at the data collection table from last time. Instruct students to reflect on the data and answer the following questions in their notebooks:

- What materials seemed to do the best at reducing peak force on the nonmoving object?

- What patterns in material structure do you see in these “top performers”?
- Think about the materials. What special features or properties of the material’s structure would make it function better than a worse-performing material?
- How do you think the structures of the materials behave in a collision that would reduce the peak forces on the objects?
- Was the peak force reduced on both objects or just on the nonmoving object?

Additional Guidance

The second and third questions on slide J are presented to get students thinking about the function of those structural patterns they are observing. Students will come back to these ideas after investigating potential force differences in a collision with a protective material.

Assessment Opportunity

Building towards: 12.A Analyze data to determine which materials reduce peak force in a collision and analyze the similarities (visual patterns across materials) in the properties of those materials (macroscopic deformability).

What to look for/listen for

- As students are individually reflecting on data, they should write about the patterns they see across multiple structures that were top performers. Students should identify that the better performers have space and/or air gaps in them and the ability to deform more than other materials that did not perform as well.

What to do

- If students do not identify similarities in better-performing materials, encourage students to go check out all 10 materials to feel and see if there are similarities in the behavior and structure of the materials.
- Have students describe the structure of 2 different materials that performed well and have them look for patterns in the structures of those materials.
- Have students apply a force (e.g., with their fingers or a spring scale) to each of the materials and describe what seems similar between the materials that were better performers.

6. Review data as a class.

4 MIN

Materials: *Up Close Images*, Force Reduction Chart

Review materials data to determine which reduced peak forces best. Display **slide K**. Ask students to turn and talk about the questions on the slide. After 2 minutes, bring the class back together and discuss the questions as a whole class.

- What materials were our “top performers” that seemed to work best to reduce peak force on the nonmoving object?

- What patterns in material structure did you see in the "top performers"?
- Did the material reduce the peak force on both objects or just on the nonmoving object?

Have students share out their ideas. Sample student responses are below.

Suggested prompts	Sample student responses
What materials were our "top performers" that seemed to work best to reduce peak force on the nonmoving object?	*The cotton balls, bubble wrap, Styrofoam, and foam earplugs did the best. (This may vary by class.)*
What patterns in material structure did you see in the "top performers"?	*Some of them had air gaps.* *Some materials seemed to be able to bend more.*
Did the material reduce the peak force on both objects or just on the nonmoving object?	*We saw the reading on the scale on the nonmoving cart change with the material attached, but the moving cart did not have a collar so we did not measure the peak force on it.* *The collar still seemed to move, but it moved less than the trials without the test materials.*

Say, *Interesting, we didn't collect data on the other cart, so we can't be sure that it reduced peak forces on both carts in the collision.*

Ask students the following question: *What do you think would happen to the peak forces on both objects if one cart had more kinetic energy than another cart before the collision, either by an increase in weight or increase in speed?*

Allow students to respond to the question. Students may bring up the following ideas:

- In Lesson 5 we figured out that the peak forces should be the same, but we are not sure if that is still the case when there is some type of material in between them.
- Maybe the padded material just protects the nonmoving object more.

Draw attention to the idea that we know from Lesson 5 that the objects involved in a collision both push on each other equally, but when we add a material in between we can't be sure that the force isn't reduced by the material, causing one side to experience more peak force than the other. We also had the carts calibrated to be the same mass as we conducted our investigation on day 1.

7. Compare forces on both objects with protective materials.

8 MIN

Materials: 1 5-N spring scale, 1 10-N spring scale, 1 force-reducing material from Materials Testing Lab

Say, *I think I have a way we can figure this out. Let's see if we add a material in between two spring scales to see if the forces are reduced on one object or both objects equally.*

Compare spring scales of different measurements. Project **slide L**. Pass out 1 5-N spring scale and 1 10-N spring scale to each group. Ask students to push the two scales together and observe the readings on each scale. Instruct students to select one protective material and place it in between the two scales. Students will use both scales to gently push in on the protective material and observe the reading on both scales. Have students swap out a scale and protective material with another group so that each group has 2 of the same spring scales and repeat the instructions.

Project **slide M**. Read the questions on the slide. Have students turn and talk about their ideas with a partner or their small group before sharing with the whole group.

Suggested prompts	Sample student responses
As you pushed in on each scale, what did you notice happening to the protective material?	*The protective material was bent or squished. Most of the materials seemed to deform.*
What did you notice about the readings on each scale?	*Even though the scales were made to measure more or less force, the reading was about the same when we pushed in on them, and it didn't matter what we had in between them. They experienced the same amount of force.*
What felt different about pushing the scales with and without the protective material between them?	*When we had the protective material in the middle, we had to push a bit more to get the same reading that we had without the protective material.* *The materials felt more squishy or bendable for the materials that reduced peak force more.*

Say, *Interesting, the really protective materials seem to reduce the forces on both objects, regardless of the strength of those objects. It also seems that the really protective materials acted a little differently than the only slightly protective materials when we pushed on them. They may have moved easier or had different properties even though they are all solids. What is special about those force-reducing materials that you identified last class?*

Ask students what they think is different about materials that reduce peak force more than other materials. Students should list things such as these:

- They are squishier.
- They seem to be lighter.
- They can bend more.

Some students may want to look at the materials more closely. Explain to students that we can get a better idea of what might be happening by looking closer at the material properties. Tell students that we do have some microscopic images that might help us explain how the properties of the better protective materials differ from the properties of materials that did not reduce peak force as well.

8. Compare materials and explain material structure.

8 MIN

Materials: science notebook, *How do we sense different textures?* (optional), *Up Close Images*

Share perceived material property differences. Display **slide N**. Distribute *Up Close Images* to partner pairs. A color copy can also be found in the *Student Procedures*. Show students the different zoomed-in images of the various protective materials that we have tested and give time for students to look over the images on the handout. Have students turn and talk with a partner about what they see in common with the protective materials.

Project **slide O**. Ask students to look back in their notebook to their responses about the specific features of materials that might be causing a reduction in peak forces. Have students share with a partner the specific features that they think contribute to the reduction of peak forces. They may revise any of their ideas at this time.

After students have had a chance to share with their partners, have students share with the whole class their ideas about perceived features. Students should identify these characteristics:

- The materials can deform more than the materials that don't reduce peak force as much.
- The materials can change shape easily.
- The materials seem to have space for air or air pockets.

Say, *Interesting. It seems that we all think that the materials have air space or pockets in them and that may contribute to how they help reduce peak forces in a collision. One material we know that definitely has air pockets is bubble wrap. Let's look at bubble wrap and cotton balls together and see what happens as we apply a force with our hands. Maybe if we use our finger sensory receptors that help us detect forces on our fingers, we can try to explain what the bubble wrap and cotton balls are doing as we apply a force.*

Additional Guidance

Extension Opportunity: In a prior activity, students manipulated the test materials by placing them in the middle of two spring scales and applying a force. Students may have noted that these test materials all feel soft or are easily pliable. This may lead to some curiosity about why certain objects feel squishy or soft. The reading *How do we sense different textures?* helps explain why we sense different sensations such as soft, hard, smooth, rough, dull, and sharp. If students are interested in learning more about how contact forces applied to the skin lead to these different sensations, they can read *How do we sense different textures?*. This reading is optional and will not affect the overall conceptual understanding of why some materials work better than other materials at reducing peak forces in a collision, but it may help answer some student questions on the Driving Question Board. Check your Driving Question Board to see if this will aid your students in figuring out the answers to any of their questions. If this reading will help address some questions on the Driving Question Board, consider assigning the reading to the class.

9. Construct individual material explanations.

14 MIN

Materials: 1 1"-square piece of small bubble wrap, 1 cotton ball, *How can materials reduce peak force on the objects they protect?*

Introduce handout. Display **slide P**. Distribute *How can materials reduce peak force on the objects they protect?*. Show students the two "Time point" boxes. Explain that the first box is for showing what the bubble wrap or cotton ball is like before a collision occurs. The second box is to identify the parts of the structure(s) they think are important and to show what happens to the structures of the bubble wrap or cotton balls as a contact force is applied. Ask students to use the second box to try to explain what the zoomed-in structures of the material are doing during a collision that helps to reduce the peak forces on the objects involved.**

*** Supporting Students in Developing and Using Stability and Change**

At this moment, students are taking the observable features that occur during a collision and their knowledge about forces and

Distribute bubble wrap and cotton balls. Pass out a small piece of bubble wrap and a cotton ball to each student. Let students know that they will get only one small piece of bubble wrap, so they need to refrain from popping the bubble wrap until we are all done explaining how they think the material helps reduce peak force on the objects.

Alternate Activity

If bubble wrap waste is an issue, consider having students not pop their bubble wrap and use the same pieces class after class as a non-consumable. Collect the unpopped bubble wrap at the end of class.

Allow students time to draft their ideas. With 2–3 minutes left in class, shift the focus to the last question. Have students try to explain the last question on the handout:

- How are these changes helping to reduce the peak forces?

Assessment Opportunity

Building towards: 12.B Construct a model to explain how the changes in the structures of cushioning materials contribute to their function (a reduction in peak forces) at a microscopic level during a collision.

What to look for/listen for

- Bubble wrap and cotton balls have a large amount of empty space or air in them and relatively small amounts of solid material across the space they take up.
- Bubble wrap and cotton balls deform easily when a small force is applied.
- Connecting structure to function, identifying a connection to reduction in peak force: e.g., less force between the cushioner and the objects it is in contact with is due to increased space, ability to deform, less-solid material, more-flexible material, and so forth.
- Possible student idea: Students may bring up particle-level connections, e.g., these materials are ones that would also exhibit less energy transfer through conduction (from prior units related to less peak force in a collision).

What to do

If students are not showing the deformation of materials on *How can materials reduce peak force on the objects they protect?*, have students use their fingers to apply a contact force to the bubble wrap or cotton ball and observe the surface of the bubble wrap and cotton ball. Ask students what the bubble wrap or cotton ball is doing: Is it breaking or is it doing something else when a contact force is applied?

At this point, students have not learned about the deformation differences between solids and gases, but this could be inferred by some students based upon prior learning in the *Storms Unit*, *Bath Bombs Unit*, and *Cup Design Unit*. Some students may be able to show the air becoming more dense upon impact in the bubble wrap or the air moving out of the cotton ball. Since this is a new use of this key concept, ask students to do their best. They will learn more about this in Lessons 13–14. There is no need for intervention on this concept until the end of Lesson 14.

applying this to create a model of microscopic changes that occur during a collision. These microscopic changes are being applied to explain how some materials reduce force on the objects that they are protecting and how their structures change over the duration of the collision.

*** Supporting Students in Engaging in Developing and Using Models**

In Lesson 11, students drafted ideas on how a material might reduce the peak force on the object it is protecting. Since then students have conducted an investigation to determine which readily available materials reduce peak force more than others and have observed the structures at a microscopic scale, looking for patterns in those structures that might contribute to a reduction in peak force. As students model the materials in the handout, the structures should become more detailed, and they should start to make connections about the ability of some materials to deform more easily than others due to changes occurring in their structure at a microscopic scale when forces are applied to them. Giving students the experience to incrementally revise this model, such as this opportunity here, will aid in their conceptual development of the target science ideas.

Collect *How can materials reduce peak force on the objects they protect?* at the end of class. Look for varying differences and explanations in the ways the protective material might be reducing peak forces. These varying ideas can be utilized to motivate student learning in Lessons 13–14. Ask students to throw away their bubble wrap as they leave class. Depending on the type of bubble wrap material, some types of bubble wrap can also be recycled.

ADDITIONAL LESSON 12 TEACHER GUIDANCE

Supporting Students in Making Connections in ELA

CCSS.ELA-LITERACY.W.8.1

Write arguments to support claims with clear reasons and relevant evidence.

CCSS.ELA-LITERACY.W.8.1.B

Support claim(s) with logical reasoning and relevant evidence, using accurate, credible sources and demonstrating an understanding of the topic or text.

LESSON 13

How (and why) does the structure of a cushioning material affect the peak forces produced in a collision?

Previous Lesson

We conducted an investigation to determine what materials reduce peak force in a collision. We compared the materials and found similarities in their structures. We determined peak force is reduced equally on both objects, regardless of size. We tried to develop a model to explain how the materials function to help reduce peak forces.

This Lesson

Investigation

3 DAYS

We develop a model to represent how the structures of materials compare in the top four performers for peak force reduction. We use scaled-up versions of these structures to generate data using slow-motion video about the unobservable mechanisms at work in the system. We carry out an investigation to determine how the amount of force applied to different points of a cushioning structure is affected by the shape of that structure.

Next Lesson

We will redesign our device using our science ideas. We will share our redesigns with stakeholders to get feedback and will use the feedback to evaluate the potential design materials. We will reflect on the consequences of those potential changes based upon stakeholder feedback.

Building Toward NGSS

MS-PS2-1, MS-PS2-2, MS-PS3-1, MS-ETS1-2, MS-ETS1-3, MS-LS1-8

What Students Will Do

13.A Construct an explanation for how (and why) the structure of a cushioning material affects the peak forces produced (function) in a collision, relating the amount of space available for deformation, the total contact time during a collision, and the peak forces produced from the addition of such structures.

13.B Develop and use subsystem models (free body diagrams) to represent how the peak contact forces on different objects in a collision compare when they have different cushioning structures between them.

13.C Critically read a scientific text adapted for classroom use to determine how concussions can result in breaks in the axons of neurons (structure) and why this can lead to memory loss (function), how a snug fit (structure) for a helmet would affect its performance (function), and how other changes in the structure of cushioning material (in a helmet) would affect its performance (function).

What Students Will Figure Out

- Protective materials tend to have a lot of space (or air) for the solid materials to deform into, which makes these materials relatively easy to deform (with little force applied to them).
- The thicker these kinds of materials are, the more they reduce peak forces because this increases total time the collision takes.
- Making a material more densely packed with smaller and smaller spaces does not necessarily reduce peak forces; such increased density may actually have the opposite effect.
- The more you can spread the peak forces out over a larger area or over more points of contact, the less force is applied to each point of contact; this can reduce the amount of damage on the material you are trying to protect.

Lesson 13 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	**NAVIGATION** Turn and talk about the properties of materials identified in Lesson 12.	A	
2	12 min	**DEVELOP AND USE A MODEL** Develop a diagrammatic model for representing small and microscopic structures in cushioning materials and develop a physical model of these to use to test the behavior of structures in a collision.	B	Smaller-Scale Material Structures poster, markers, 1 roll of transparent tape, 8-12 trimmed sheets of paper to fit in each cell on the poster, 2 rectangular strips (1″ x 9.25″ each) of material cut from a plastic folder cover
3	4 min	**PREDICT OUTCOMES AND PLAN FOR DATA COLLECTION** Make predictions on how adding the rings between two colliding objects would affect the forces between them and set up data collection tables.	C	half-sheet data table from *Observations from Adding Additional Ring Structures*
4	10 min	**RECORD AND ANALYZE DATA FROM SLOW-MOTION VIDEOS** Record data from five slow-motion videos for the five collision conditions. Analyze and interpret the data in the whole group.	D	*Observations from Adding Additional Ring Structures*, computer, projector, five slow motion videos (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**)
5	10 min	**ANALYZE AND INTERPRET THE DATA FROM THE VIDEOS** Analyze and interpret the patterns in data from the five slow-motion videos as a whole class.	E	
6	5 min	**INDIVIDUAL PROGRESS TRACKER**	F	
				End of day 1
7	20 min	**DEVELOP AND USE FREE BODY DIAGRAMS** Develop free body diagrams to represent the forces between the subsystem structures and between those structures and a cushioning material.	G	*Free body diagrams for collisions with and without cushioning structures*, 2 colored pencils (any color), Consensus model from Lesson 5 with the free body diagram on it, chart paper, markers

Part	Duration	Summary	Slide	Materials
8	6 min	**USE FREE BODY DIAGRAM MODELS TO MAKE PREDICTIONS** Create a series of free body diagrams to show how the relative strength of the peak forces on each subsystem in a collision with three rings in the cushioner in the system would compare to the other conditions.	H	*Free body diagrams for collisions with and without cushioning structures*
9	4 min	**SIZE PREDICTIONS** Consider a system where there is a limited amount of total space available for adding cushioning material to it.	I	*Free body diagrams for collisions with and without cushioning structures*
10	7 min	**ANALYZE SIZE DATA AND UPDATE PROGRESS TRACKER** Add to the Progress Tracker how and why the structure of different cushioning materials affects peak forces in a collision.	J	
11	3 min	**NAVIGATION** Make predictions about changes to the structure or shape of a cushioning material and the related effect on peak forces in a collision.	K	
				End of day 2
12	3 min	**NAVIGATION** Discuss reasons for predictions about how changing the structure of cushioning material will affect peak forces in a collision.	L	
13	5 min	**INTRODUCE A CONTROL CONDITION AND MAKE PREDICTIONS**	M	*Exploring shape of a cushioning material*, Other Shape Tests
14	10 min	**TEST THE FIRST THREE STRUCTURES**		*Exploring shape of a cushioning material*, Other Shape Tests
15	5 min	**TEST THE LAST TWO STRUCTURES**		*Exploring shape of a cushioning material*, Other Shape Tests
16	18 min	**PROGRESS TRACKER UPDATE** Update individual progress trackers and use these entries to contribute to a class discussion to add a whole class progress tracker update.	N	chart paper, markers
17	5 min	**NAVIGATION** Consider how we could apply our ideas to the design of a protective headgear for preventing concussions in sports-related collisions and how we might apply what we figured out to our own design problems.	O-P	*Reading: Anatomy of a Bike Helmet*
				End of day 3
		SCIENCE LITERACY ROUTINE Upon completion of Lesson 13, students are ready to read Student Reader Collection 5 and then respond to the writing exercise.		Student Reader Collection 5: Structures and Forces

Lesson 13 • Materials List

	per student	per group	per class
Other Shape Tests materials	• safety goggles		• 5 weighted plates (washers secured to the plate with sticky putty and a dime-size piece of sticky putty secured to the other side) • 5 preassembled ring structures • 1 digital scale • 5 weighted plates (washers secured to the plate with sticky putty • and a dime-size piece of sticky putty secured to the other side) • 1 piece of 8″ x 11″ x ½″ Styrofoam panel per class (consumable) • 3 5-N push-pull spring scales • 1 fine-tip permanent marker • 3 weighted plates (washers secured to the plate with sticky putty
Lesson materials **Student Procedure Guide** **Student Work Pages**	• half-sheet data table from *Observations from Adding Additional Ring Structures* • science notebook • *Observations from Adding Additional Ring Structures* • *Free body diagrams for collisions with and without cushioning structures* • 2 colored pencils (any color) • *Exploring shape of a cushioning material* • *Reading: Anatomy of a Bike Helmet*		• Smaller-Scale Material Structures poster • markers • 1 roll of transparent tape • 8-12 trimmed sheets of paper to fit in each cell on the poster • 2 rectangular strips (1″ x 9.25″ each) of material cut from a plastic folder cover • computer • projector • five slow motion videos (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**) • Consensus model from Lesson 5 with the free body diagram on it • chart paper

Materials preparation (60 minutes)

Online Resources

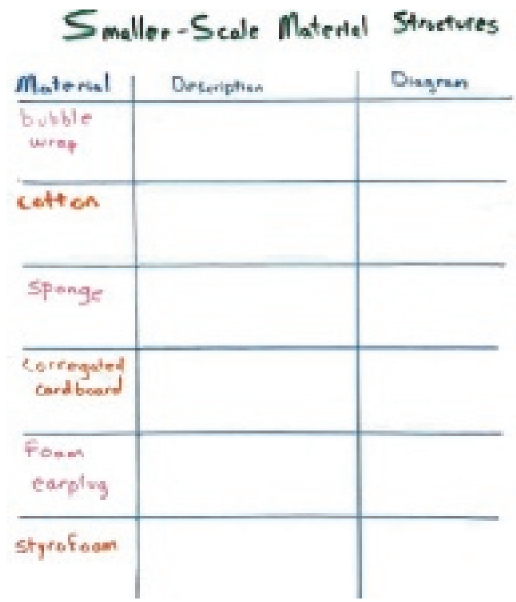
Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Look back at student work turned in from Lesson 10. Identify areas of controversy over how the materials work to make connections in this lesson.

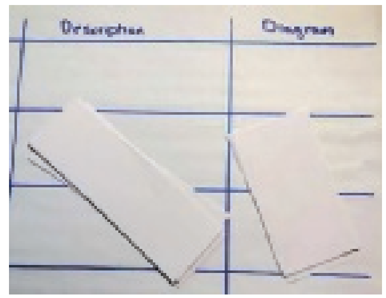
Make 1 copy of *Observations from Adding Additional Ring Structures* per two students. There are two data tables on this, so cut the copies in half so that you have one half sheet (one data table) per student.

Prepare a Smaller-Scale Material Structures poster for the top four peak force reduction materials for your classes. The example shown here has space for the top six peak force reduction materials, rather than only your top four.

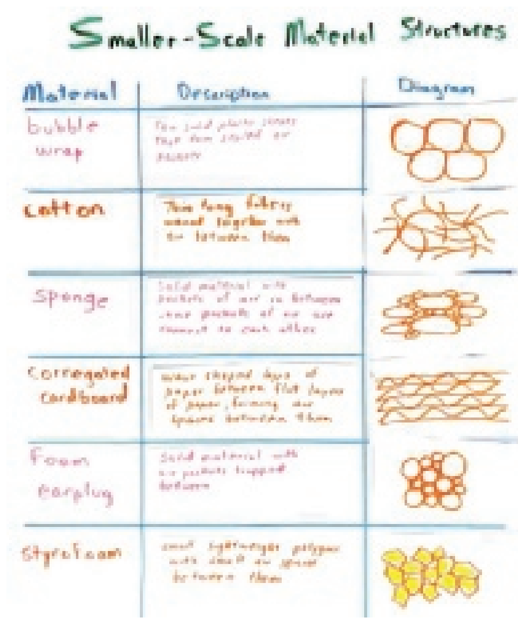


Cut pieces of copy paper so that you have enough to fit in each cell of this table for each class. This will allow you to co-construct the representations with each class during the related discussion.

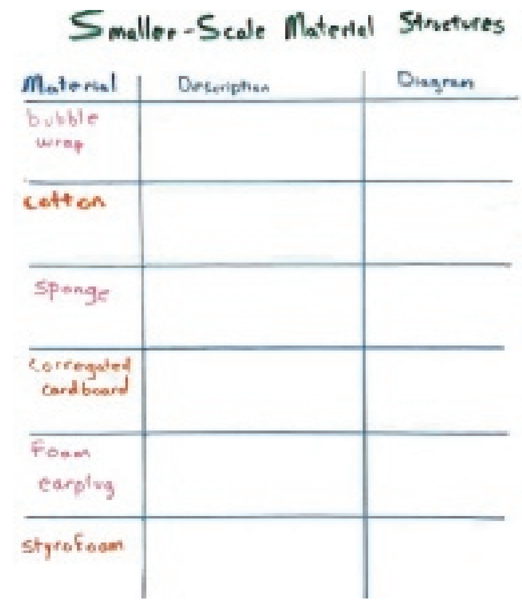
You will remove the half sheets of paper between classes so that you can reuse the poster between classes.



The completed cells are shown below. Ideally you co-construct each of these with each new class. It can be helpful to have one set of these prebuilt, however, in case you need to use those if time is short. Keep the final class's representations posted in the classroom as an anchor chart for students to refer to in the remaining lessons of the unit.



Prepare a Smaller-Scale Observations from Adding Additional Ring Structures poster similar to the poster shown here, for the top four peak force reduction materials for your classes. The example shown here has space for the top six peak force reduction materials, rather than only your top four.



Put the consensus model that you made from Lesson 5 with the free body diagrams on it in a place that you can reference it later in the lesson.

Day 3: *Other Shape Tests lab*

- **Group size**: Whole class
- **Setup**: Set aside 1 piece of 8″ x 11″ x ½″ Styrofoam panel per class (consumable). Set aside 3 5-N push-pull spring scales, 1 digital scale, and 1 fine-tip permanent marker to reuse across all classes.
  - Preparation of ring structures (The complete set of 5 preassembled ring structures will be two 6-ring triangles, one 3-ring structure, one 2-ring structure, and one single ring.)

- Cut out 20 strips from a plastic folder cover, each 1 inch wide and 9.25 inches long.
    - Leave 2 strips unmodified for demonstration purposes later to show how a ring is made from a strip.
    - Roll each remaining strip (18 total) into a ring, overlap the ends of the strip 0.5 inches, and tape the inside and outside of it with a 3-inch piece of tape.
    - You will now have 18 rings roughly 2.75 inches in diameter.
    - Make 3 sets of these: Place two rings side by side and tape them together along the edges where they meet. Use 2 half-inch pieces of tape to do this.
    - Make 3 sets of these: Place three rings side by side and tape them together along the edges where they meet. Use 4 half-inch pieces of tape to do this.
    - Now build two triangles using a set of 3 rings, a set of 2 rings, and a single ring for each triangle. Use half-inch pieces of tape to tape them together along the edges where they meet. Your completed ring triangle structures will look like the bottom photo:

- Preparation of weighted plates: Make 3 weighted plates, 200 grams each. Do the following for each plate:
    - Attach two large washers to one side of a plastic electrical cover using a dime-sized piece of sticky putty.
    - Place a dime-sized piece of sticky putty on the other side of the plate too to use later for sticking the rings to.
    - Mass the system on a digital scale.
    - Adjust the amount of sticky putty on each plate setup so that every weighted plate you make has the same amount of mass on it.
- **Safety**
    - Wear safety goggles or glasses during the setup, hands-on, and take-down segments of the activity.
    - Carts can fall off the tables if a brick is not placed at the end of the track. Make sure each station has a brick at the end of the track.
    - Bricks are heavy and can cause injury when dropped on body parts.
    - Make sure all bricks are away from edges of tables or areas where there is a drop risk. Make sure all fragile items are removed from the test area.
    - Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
    - Immediately pick up any items dropped on the floor so they do not become a slip or fall hazard.
- **Storage**
    - Dispose of the damaged Styrofoam panel. All other materials can be stored and reused indefinitely.

Lesson 13 • Where We Are Going and NOT Going

Where We Are Going

Three different relationships related to how the structure of a cushioner can affect its function are introduced in this lesson in order to give students a variety of competing trade-offs to consider in their own designs:

- Thicker cushioning materials should reduce peak forces more.

- The structure of such cushioning materials can be changed at a microscopic and/or a macroscopic level, and both changes may impact the peak forces in a collision.
- The shape of a structure can distribute contact forces over a smaller or larger area, thereby increasing or reducing the amount of peak force on a specific section of material.

This latter idea expands the definition of *breaking point*, which up until now has been defined as the amount of peak force an object can withstand before reaching its elastic limit. While that is true for fixed-volume or fixed-shape samples of a material, engineers typically determine breaking points by comparing the amount of stress, or force per unit area, between different materials in relation to the amount of deformation the samples undergo. This allows them to make comparisons more easily between material samples with different cross-sectional areas.

This lesson advances students' work in systems and system modeling by engaging them in developing free body diagrams for a multi-object system undergoing contact force interactions (more than two objects in the system), and it gives them an opportunity to define the number of subsystems they will treat a chain of 3 rings as when they build these diagrams.

It also advances their understanding of the role of models in engineering related to the role of physical scale models that are often constructed to understand physical systems better and to generate data to use to guide engineering solutions. Students worked with examples where models were used to scale down phenomena that were too large to see (tsunami formation and propagation and design solutions for protecting vulnerable coastlines). But the work in this unit helps them understand that such scale models can also be used to scale up smaller-scale phenomena. In particular, students are introduced to the idea that working with larger-scale analogs of microscopic structures could help them understand what might be happening at a much smaller scale within the microscopic structures of our top force-reducing materials. They are told that this is something that engineers and scientists often do when they want to understand how something works at a scale that is too small to see. They develop larger-scale models and test how those work and use the results of these tests to better understand the unobservable changes occurring in those smaller structures.

Students develop a line of evidence that explains how cushioners work by relating the amount of space available in microscopic structures within cushioning material for those structures to be able to deform in a collision, the amount of peak force they produce, and the total amount of contact time during the collision. This leads them to establish a generalized statement of the relationship among net forces applied to an object, the time those forces are applied, and the amount of change in motion. The form of the statement "When weaker forces are applied to an object it will take more time to change its motion" can be used to explain other kinds of motion changes beyond the cushioning context they are exploring now.

Where We Are NOT Going

The previous statement is a qualitative description of a relationship that will be explored further in related physical science ideas in the high school grade band related to the idea that momentum change (or change in velocity for an object of fixed mass) is due to impulse experienced by the object, which is measured as the amount of force times the length of time it is applied. This is beyond the focus of this unit.

LEARNING PLAN FOR LESSON 13

1. Navigation

5 MIN

Materials: None

Revisit a previous question from the end of the last lesson. Show **slide A**. Discuss this question as a class.

Suggested prompt	Sample student response
What structures did the materials seem to have in common that were good at reducing peak forces?	*They have a lot of space or air between the smaller parts of it that are made of solid fibers or solid sheets of material.*

Continue the discussion around how this type of structure can help reduce peak forces in a collision.

Suggested prompts	Sample student responses
How would this type of structure help reduce peak forces in a collision?	*The spacing or air in it allows it to squish more easily.* *There is less matter to push back.* *There is less solid material actually touching the other object.* *The matter that is there gives easily, which means it pushes back with less force for a certain amount of deformation.*
How is it possible that these materials can cause the maximum force between the objects to decrease when the kinetic energy of the objects before the collision remains unchanged?	*(Accept all answers.)*

Say, *OK, so we know that there are certain structures in common with the materials that reduced peak forces the best, like air or space between the walls, and we think this might have something to do with why they reduce peak forces in a collision even when the kinetic energy of the objects before the collision doesn't change. But how is it possible that these materials are actually causing the strength of the maximum peak force between the objects in a collision to go down? Let's try and develop a model for what might be happening within the structures that make up those materials that can help us figure out how this is possible.*

2. Develop and use a model.

12 MIN

Materials: Smaller-Scale Material Structures poster, markers, 1 roll of transparent tape, 8-12 trimmed sheets of paper to fit in each cell on the poster, 2 rectangular strips (1" x 9.25" each) of material cut from a plastic folder cover

Meet in a Scientists Circle for a Building Understandings Discussion. Show **slide B**. Introduce the need for a model to represent similarities in the small and microscopic structures. Say, *Let's try to draw a representation of the sort* *of general structures we all agree are a part of these materials at a small or microscopic level that are responsible for why they behave in similar ways.*

Hang the "Smaller-Scale Material Structures" poster on the wall where students can see it. Ask students to describe what the structure of each of the top 4 force-reducing materials looked like when we examined a cross-section of each material. It is expected that the top performers will be Styrofoam, bubble wrap, foam ear plugs, and cotton balls. But prompts and responses are included below for other possibilities too.

Suggested prompts	Sample student responses
What does the structure of bubble wrap look like if we examined a cut-away section of it?	*Thin, solid sheets of material that form a surface that is sealed up to form closed air pockets.*
What does the structure of a cotton ball look like if we examined a cut-away section of it?	*Thin and long fibers that are wound together and that have open space between them.*
What does the structure of corrugated cardboard look like if we examined a cut-away section of it?	*Wavy ripples of paper with a flat layer of paper between them and with arches or gaps between the ripples.*
What does the structure of a foam earplug look like if we examined a cut-away section of it?	*Different-size open spaces surrounded by squishy material.*
What does the structure of Styrofoam look like if we examined a cut-away section of it?	*Small, lightweight spheres or polygons with air pockets between them.*

For each description that students share, draw a diagram on a half sheet of paper and tape it in the row for that material (or share a pre-drawn one). Do the same for each written description. You could ask student volunteers to be ready to help write a verbal description of what you drew for a particular row to help speed up the construction of the chart.

Again, it is expected that the top performers will be Styrofoam, bubble wrap, foam ear plugs, and cotton balls. Limit the entries you add to this poster to the top 4 force-reducing materials for your class.

*** Supporting Students in Engaging in Developing and Using Models**

This is an important opportunity to help students see that another type of model that engineers develop in science is one that can be used to visualize what is happening at a scale too small to see. Here students are using a scaled-up model to visualize what happens with peak forces when using materials with air gaps or pockets. It also prepares students to think like an engineer by using multiple models to generate data to figure out how part of a system works in order to know how to apply the design and optimization of a solution necessary to address an identified problem.

Additional Guidance

Drawing a 2-dimensional, cross-section representation of the structure for each of the materials will help foreground the similarities between them that might not be apparent from a photograph that also shows some of the three-dimensional structure of the material, like in the bubble wrap or cotton ball.

Remember, between classes you will remove the half sheets of paper you added to this poster so that you can reuse the poster for all classes. Keep the final class's representations posted in the classroom as an anchor chart for students to refer to in the remaining lessons of the unit.

Develop a scaled-up physical representation of a common structural element. Say, *OK, Let's make a scaled-up representation of some of these structures. Here is a strip of plastic material from a folder cover, if I bend it into a circle and tape it, which parts of which materials on our chart would this best represent? Which is it kind of close to representing?*

Demonstrate this with one the rectangular strips (1″ x 9.25″) of material cut from a plastic folder cover. Bend it into a circle and then tape both ends of it together.

Students will say it best represents a small piece of the small or microscopic structure of the bubble wrap or the foam earplugs because there are circular gaps of air or space. Alternatively, or in addition, they may say it is close to the structure of another one of the materials. Ask students what about the structure you made represents an important aspect of the other materials, such as corrugated cardboard. Students will say that the structure you made forms a space that makes a semi-closed pocket of air or gap or space surrounded by solid material or walls, and many of the materials have a semi-closed pocket of air or gap or space surrounded by solid material.

Emphasize that even though this physical model doesn't represent the structure of the cotton fibers as well, it still includes one key feature, namely, it has a lot of empty space in it in proportion to the amount of solid matter.

Demonstrate by taking the second of the rectangular strips (1″ x 9.25″) of material cut from a plastic folder cover, and bending it into a circle and then taping both ends of it together. Then tape this circle against the first circle you previously made.

Ask students which materials have a repeating pattern in their microscopic structure like the one we just built, even if the exact shape and size of the air pockets in the structure might be slightly different. Students will say it represents most of the materials, except maybe for the cotton ball or Styrofoam. In the case of the Styrofoam students may say that the ratio of solid material to air or empty space isn't right and that to represent Styrofoam, we need more solid and less air between the repeating structures. Say, *We've made an argument here that this larger-scale structure represents something important we are seeing in the small and microscopic structures of many of these top force-reduction materials. They all have a large amount of air or space gaps in between the solid matter, just like this structure does. Now that we have analyzed a large-scale physical model that represents this important aspect of the structure of peak force reducers, we could use it to understand what might be happening at a much smaller scale within those small and microscopic structures of our top force-reducing materials. This is something that engineers and scientists often do when they want to understand how something works at a scale that is too small to see. They develop larger-scale models and test how those work and use the results of these tests to better understand the unobservable changes occurring in those smaller structures.*

Take apart the circles you made so you demonstrate taping them together for your next class.

3. Predict outcomes and plan for data collection.

4 MIN

Materials: half-sheet data table from *Observations from Adding Additional Ring Structures*, science notebook

Show **slide C**. Use this to cue students to turn and talk about the following questions:

- Would adding ring structures to the system, as shown in B and C, affect the peak forces in the collision? Why or why not?
- Would attaching these structures to the stationary object (brick), as shown in D and E, instead of to the moving object affect the peak forces in a collision? Why or why not?

Listen for different predictions in the partner talk.

Prepare to record data. Pull students together. Share that you heard different predictions in the partner discussions and suggest that we should try to collect some observations to see which of these predictions are supported or refuted. Distribute a half-sheet data table from *Observations from Adding Additional Ring Structures* to each student and have them add it to their notebook.

4. Record and analyze data from slow-motion videos. 10 MIN

Materials: science notebook, *Observations from Adding Additional Ring Structures*, computer, projector, five slow motion videos (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**)

Show **slide D**. Say, *Let's start by watching the first two conditions outlined in our data table.*

Show video A. Give students a minute to record their observations.

Show video B. Give students a minute to record their observations.

Before showing any other videos, discuss what students noticed to motivate watching these first two videos a second time with the goal of recording data that would allow us to determine the total length of collision time in each condition.

Suggested prompts	Sample student responses
What did you notice about the peak forces in the two collisions?	*There was less peak force in the system with a ring in it than in the system without a ring.*
Since our very first lesson, we've been trying to visualize what was happening right at the moment of first contact to a split second after this happens. What did you see happening to the ring structure during the time the collision was occurring?	*The ring was deforming and then after it reached a maximum amount of deformation it started returning to its original shape, which is when the cart started moving backward.*
Were there any differences you noticed in the amount of time it took for the collision, either in terms of how long the objects were in contact with each other or in terms of how long it took for the collision to produce its peak forces?	*It seemed like the system with a ring in it took longer than in the system with none.*
What evidence could we collect from the videos to see if there is a difference in the amount of time those things took?	*We could record the times we see on the phone or stopwatch running in the video when the contact first occurs and when it reaches peak force and/or when contact is broken off.*

Say, *Let's watch these two videos again and record additional observations regarding the amount of time the collision took. You decide if you want to record how long it took to reach peak force after first contact occurred or if you want to record how* *long it took until the contact between the objects ends. Either way you will have to record at least two times. That will allow you to calculate and compare the length of time these events took in different collision conditions.*

Ask students to stand in a semi-circle around the screen you are projecting the videos on before showing the videos again. Students can ask you to pause the videos at any time so they can take a closer look. Encourage students to go up to the screen and point to things in the video when they ask you to pause it. Students are likely to ask you to pause at each of these points in time:

- The point of first contact between the leading edge of the cart system and the leading edge of the brick system
- The point where the peak force is reached
- The point at which contact is broken between the ring on the brick and the cart subsystem

Show videos A and B again.

Then show videos C, D, and E.

(See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**)

5. Analyze and interpret the data from the videos. 10 MIN

Materials: science notebook

Facilitate a discussion of the patterns across the five collision cases. Have students return to their seats. Show **slide E**. Cue students to read through the questions on their own and study the data table for a minute independently. Then discuss the questions on the slide as a whole group.

Suggested prompts	Sample student responses
What patterns did you notice in the peak forces produced across all five collision conditions?	*The peak forces decreased with more rings.* *Two rings produced less peak force than one ring, which produced less peak force than no rings.* *The amount of peak force was reduced just as much, regardless of whether the rings were on the stationary object or the moving object.*
How did the motion of the cart system change after the system reached the point at which peak forces occurred?	*The direction of the cart system reversed its motion.* *It started moving in the opposite direction.*

Suggested prompts	Sample student responses
What patterns did you notice in the total time it took to reach that point in the collision?	*The total time the objects were in contact with each other increased as you added more rings.*
Was there a similar pattern in the total time it took for the collision from when contact was first made to when the contact was broken?	*Yes.*

Additional Guidance

Some students may also notice that the maximum amount that every structure in the system deformed decreased when the system went from having 1 ring to 2 rings in it. If they notice that now, make note of it too, but don't dwell on it yet. You will return to look for evidence of this on day 2 of this lesson when you develop free body diagrams of these structures for each of these conditions.

Key Ideas

Listen for the following key ideas in this next part of the discussion. When students share them, ask others to restate each of them.

- *Structures like rings provide space for the protective material to deform.*
- *The more of these structures there are in a cushioner, the longer the contact time during the collision.*
- *The more of these there are in a cushioner, the lower the peak forces that are produced by the collision.*
- *When weaker forces are applied to an object it will take more time to change its motion.*
- *When stronger forces are applied to an object it will take less time to change its motion.*

First focus on asking students to summarize the relationships they discovered among the number of structures that have space in them to deform, the length of time the deformation is occurring over, and the peak forces produced in the collision.

Suggested prompts	Sample student responses
What can we conclude will happen to the peak force in a collision then when we add more structures that have gaps, space, or air pockets in them in between the two colliding objects?	*The peak forces on things in the system will go down.*
What can we conclude will happen to the amount of time the collision takes when we add more structures that have gaps, space, or air pockets in them in between two colliding objects?	*The total time the objects were in contact with each other during the collision from the start of collision to end will increase.*

Now shift to asking students to generalize the relationship between the strength of force applied to an object and the time it takes to change the motion of the object.

Suggested prompts	Sample student responses
In every case the motion of the cart changed in the collision. It went from moving in one direction to moving in the reverse direction. Let's try to summarize what this tells us about the relationship between the time it takes to change the motion of an object and the strength of forces used to do it. So when weaker forces are applied to an object to change its motion, what will happen to the amount of time it will take to do that?	*It will take a longer amount of time.*
When stronger forces are applied to an object to change its motion, what will happen to the amount of time it will take to do that?	*It will take a shorter amount of time.*

6 • Individual Progress Tracker

5 MIN

Materials: science notebook

Update individual Progress Tackers. Say, *These ideas are all based on observing these large-scale structures. But let's remind ourselves that these weren't the specific structures we were interested in explaining at the start of our lesson. We were initially interested in explaining how and why the microscopic structure of an effective cushioning material decreases the peak forces in a collision. Let's take a moment to think about how we apply what we figured out to those materials.*

Show **slide F**. Give students the remaining time to add an entry to their individual Progress Trackers in their science notebook related to the lesson question:

- How (and why) does the structure of a cushioning material affect the peak forces produced in a collision?

Ask students to leave their notebooks for you to review before the next class.

Assessment Opportunity

Building towards: 13.A Construct an explanation for how (and why) the structure of a cushioning material affects the peak forces produced (function) in a collision, relating the amount of space available for deformation, the total contact time during a collision, and the peak forces produced from the addition of such structures.

What to look for

- Good cushioning (force-reduction) materials have space available in them for deformation.
- More space available for deformation is related to an increased contact time during the collision.

- Increases in contact time in the collision are related to decreased peak forces produced in the collision.
- Optional: Students may argue that thicker cushioning materials with spaces or air gaps in them available for deforming should therefore reduce peak forces more in a collision.

What to do: The individual Progress Tracker is designed to be a space for students to make sense of what they have figured out, and therefore these individual entries may or may not be shared with and reviewed by the teacher at different points in the unit. For this specific entry, use what students have entered individually as a formative assessment piece that is not scored but instead is used to ensure students are ready to move on the next day. At the end of this lesson, the class will co-construct a three-box Progress Tracker to record what the class has come to consensus on about what they have figured out about cushioners. At that point, students may turn to this entry and use what they have recorded here as they help the class co-construct. Because this entry serves as a formative assessment piece, you may choose to just read through them to gauge where students are at and/or, for those that might benefit from thinking more about the question, you could leave question prompts as feedback directly in their notebook on this entry.

End of day 1

7. Develop and use free body diagrams.

20 MIN

Materials: *Free body diagrams for collisions with and without cushioning structures*, 2 colored pencils (any color), Consensus model from Lesson 5 with the free body diagram on it, chart paper, markers

Say, *At the end of our last class you summarized what you figured out about how and why the structure of a cushioning material affects the peak forces produced in a collision. Let's use what you figured out to think about what is happening to each structure in the system from a free body diagram perspective and then use that form of system thinking to make predictions about what would happen when we change the structure of the materials we are using in other ways*. Show **slide G**.

Distribute *Free body diagrams for collisions with and without cushioning structures* to each student and have them add it to their notebook.

Gather students in a Scientists Circle. Bring the Consensus model from Lesson 5 with the free body diagram on it to the circle.

Key Ideas

Purpose of this discussion: Help students apply use of free body diagrams for representing the forces in subsystems in Lesson 5 to the subsystems from the most recent investigation.

These representations include showing external forces on each subsystem as in the following:

- The direction of the force arrow indicates the direction of the force applied on the object.
- Differences in length of an arrow represent differences in the relative magnitude of a force.
- The tip of the arrow indicates the surface on which the contact force pushes.

Ask students to compare the objects and subsystems represented for each of the conditions shown in the system diagrams on the handout and describe what is simplified in these representations.

Suggested prompts	Sample student responses
Look at the chart on your handout. These are simplified diagrams showing the different structures that were added between the cart subsystem and the brick in the videos we analyzed. What is different in each diagram that shows this?	*A ring is added in one. And two rings are added in the other.*
Though the rings and brick have a similar shape to what we saw in the video, notice that the cart and spring-scale subsystem has been simplified to show the cart and the spring scale. What are some parts of the cart subsystem that are left out of this diagram?	*The wheels.*
In addition to the wheels, what are other things the wheels make contact with that are also left out of the diagram?	*The track.*
So in the first diagram, we see only two subsystems being represented. How many clearly labeled subsystems are there in the next diagram?	*Three.*
And in the third diagram?	*Four.*

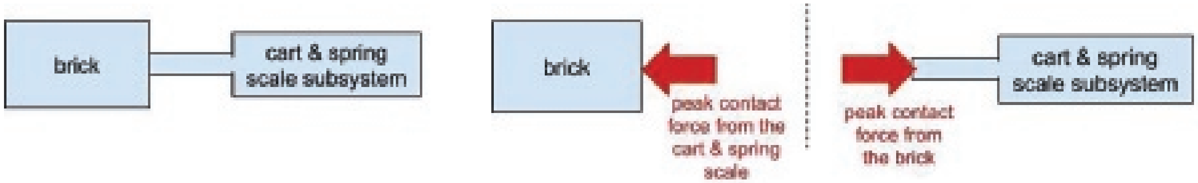
Introduce another modeling convention in free body diagrams. Say, *These sorts of simplifications, leaving out some details and objects and paying attention to a subset of them in a system, are commonly done when engineers or scientists make free body diagrams of moving objects. Many times the objects in the system are simply shown as rectangles or circles rather than including other details that don't necessarily help visualize where the force interactions are occurring in the system.*

Connect to other examples of simplified representations of objects and interactions from work students have done in prior units. Say, *When this sort of simplified representation is used, however, it's important to label each object in the system that you are developing a free body diagram for. You've made similar simplifications for other system models you've developed in other units. For example, in your work on Palm Oil Unit when modeling interactions in the palm oil and native ecosystems for orangutans, what are some of the populations of organisms in the ecosystem that you showed interactions between with just a simple rectangle?* Students will say things like orangutans, palm oil trees, fruit trees, insects, tigers, rats, and pigs as just a few examples.

Co-develop free body diagrams for the two subsystems in the ringless collision. Use the following prompts to elicit students' ideas to add to the creation of two free body diagrams for this condition on a piece of blank chart paper.

Suggested prompts	Sample student responses
How many separate free body diagrams should we draw for the first collision case?	*Two.*
Is one object applying a force on another object without the other object applying a force back?	*No.*
And how should the strength of the forces on each object compare?	*They should be the same.*
How do we represent that the forces on each object are equally strong?	*Use arrows of equal length.*

The completed free body diagram should look something like the illustration here. Students should add something similar to the first row in their table on *Free body diagrams for collisions with and without cushioning structures*.



Co-develop free body diagrams for the three subsystems in the single-ring collision. Use the following prompts to elicit students' ideas to create three free body diagrams for this condition on the chart paper below the first free body diagrams.

Suggested prompts	Sample student responses
Let's treat the cushioner, or the ring, as a single subsystem with its own free body diagram. If we do, then how many total separate free body diagrams should we draw for the second collision case?	*Three.*
OK, let's draw each of those and label them. And let's start with the cart and spring-scale subsystem. Which subsystem is making direct contact with the tip of the spring-scale plunger when it registers a peak force?	*The ring.*
Which way is the ring pushing on the tip of the spring-scale plunger?	*It is pushing on it with a force pointed to the right.*
How should the strength of this force compare to what we showed in the diagram above?	*There should be less peak force.*

Suggested prompts	Sample student responses
How would we represent this in our diagram?	*We should show this with a smaller length for an arrow.*
Does the spring-scale launcher tip push back on the ring?	*Yes.*
In what direction and with how much force? The same amount as we showed on the spring-scale plunger? More? Less?	*The opposite direction with just as much force as we showed on the cart and spring-scale subsystem (which is less than in the first diagram).*
OK, that is one force arrow we have added to the ring now. But what else does the ring make contact with when the system reaches peak forces?	*It makes contact with the brick.*
And we know that the ring pushes back just as much on the things that compress it, whether it is attached to the motionless thing or to the previously moving thing. So how would the amount of force that the ring is pushing back on the brick here compare to how much the ring was pushing back on the cart?	*It should be an equal amount of force.*
So is that amount of force between the brick and the ring only on the brick or only on the ring, or is it on both?	*Both.*

The completed free body diagram should look something like the illustration here. Students should add something similar to the second row in their table on *Free body diagrams for collisions with and without cushioning structures*.

Introduce two different ways to model the two-ring condition. Say, *For the two-ring condition, you could choose to represent the two rings as a single subsystem* ***or*** *you could represent them as two separate subsystems. In the first case you would need to show three free body diagrams, while in the latter you would need to show four. You and your partner should decide how you want to model that condition, but remember to look back at our results from the video so that your model accurately represents the relative strength of all the peak contact forces from the interactions between each subsystem in your model.*

Give students 5 minutes with an elbow partner to complete the third row in the handout. Emphasize that this is one part of a formative assessment you want to collect.

After students have completed the third row, ask if there are any questions and if students feel confident they could use this way of representing forces in each subsystem to predict what would happen if there were three rings of the same size chained together on either the spring scale or the brick.

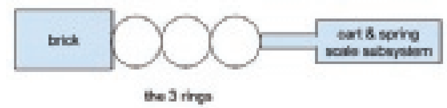
8. Use free body diagram models to make predictions. **6 MIN**

Materials: *Free body diagrams for collisions with and without cushioning structures*

Show **slide H**. Have students return to their seat to complete *Free body diagrams for collisions with and without cushioning structures*. Emphasize that this is the second part of the formative assessment you want to collect. Collect *Free body diagrams for collisions with and without cushioning structures* when students have completed their work.

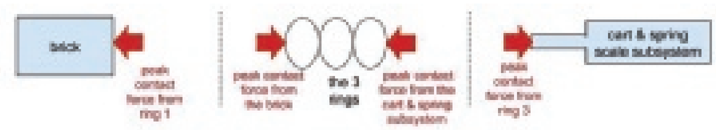
Assessment Opportunity

Building towards: 13.B Develop and use subsystem models (free body diagrams) to represent how the peak contact forces on different objects in a collision compare when they have different cushioning structures between them.

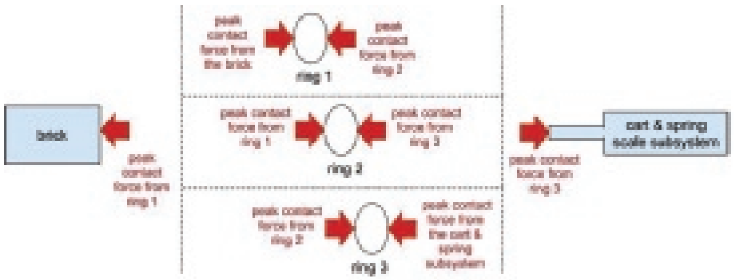


What to look for: Look for a system model that includes the following structures and subsystems:

Look for free body diagrams. In every approach used, the length of the force arrows should be shorter than any previous condition. One approach would be to treat the three-ring cushioner as a single subsystem. If so, look for the following in student responses.



Another approach would be to treat the three-ring cushioner as three separate subsystems. If so, look for the following student responses below.



What to do: For students who struggle with creating these free body diagrams, pair them up with another student who has been finding success with developing these diagrams and ask them to compare their models using the "partner feedback process" from slides D and E they used in lesson 10. This will provide a structured way for each student to share their diagram, compare each other's diagrams, ask questions, and then revise their models.

9. Size Predictions **4 MIN**

Materials: *Free body diagrams for collisions with and without cushioning structures*

Introduce the context for another shape consideration. Show **slide I**. Read the text at the top of the slide, *Some design solutions for protective devices may have criteria or constraints that impose a limit to the amount of space available for adding cushioning material to a system. Let's consider a system where there is a limited amount of total space available for adding cushioning material to it.* Ask students to discuss the questions on a slide with a partner for a couple minutes.

Then discuss these questions briefly as a class.

Suggested prompts	Sample student responses
If we wanted to double the number of air gaps or spaces in the structure of a cushioning material used in the space, how would the size of those air gaps or spaces have to change in order to fit them in?	*They would have to get smaller.* *They would have to shrink.*
Do you think that change would also affect the reduction in peak forces that those structures provided in a collision?	*(Accept all predictions.)*

10. Analyze size data and update Progress Tracker.

7 MIN

Materials: science notebook

Introduce size data. Show **slide J**. Give students the remaining time to discuss the data on this slide with a partner and to add to their Progress Tracker (while still talking with a partner) under the entry for this question:

- How (and why) does the structure of a cushioning material affect the peak forces produced in a collision?

11. Navigation

3 MIN

Materials: None

Make initial predictions about changes to the structure or shape of a cushioning material and the related effect on peak forces in collision. Show **slide K**. Emphasize that students should discuss this question with a partner now so that we can share what ideas partners came up with as a whole class next time:

- Do you think other changes to the structure or shape of a cushioning material would affect how much it reduces peak forces in a collision? Why or why not?

End of day 2

12. Navigation

3 MIN

Materials: None

Share predictions from the end of last class. Show **slide L**. Discuss this question as a whole class, getting a few different reasons for the predictions that students made. Accept all responses.

- Did you and your partner think that other changes to the structure or shape of a cushioning material would affect how much it reduces peak forces in a collision? Why or why not?

13. Introduce a control condition and make predictions.

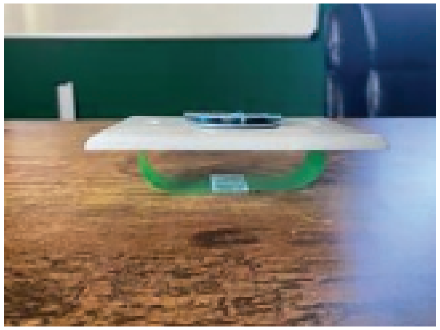
5 MIN

Materials: Other Shape Tests, *Exploring shape of a cushioning material*, science notebook

Say, *Since we have some different predictions about the impact that other shape changes in a cushioning material will make in a collision, let's collect some additional data on this question. Let's test five different structures where we again use rings as a repeating substructure across each structure we test. These are the structures we are going to test.*

Show students the 5 structures we will be testing. Ask students to describe the relative size and arrangement of the rings in each structure. Students will say that they are the same size and many are taped together.

Motivate testing a control. Say, *For each of these structures let's place them between a plate and the table and apply the same amount of force on the system and see how each structure will respond. Before we test all of these structures, let's take some initial observations for one of the structures to serve as a control condition and then use this to make some predictions about how the rest of the structures will function in comparison to that.*



Demonstrate the single-ring condition by placing one of the weighted electrical plates on it. Use the sticky putty on the back side of the plate to secure the ring to the bottom of it. Now, on the table, balance the weighted plate on top of the ring. Describe how you are trying to balance the plate on the ring without pushing down or lifting up more on the system to do so. Ask students to describe what they notice happening. They will say the ring deformed.

Remove the weighted plate. Say, *I massed each plate before class and adjusted the amount of putty on each so that they all have the same weight. We can therefore use these to apply the same amount of force to these four other structures.* Optional: Demonstrate this for a couple of plates by placing them on a digital scale, if needed.

Distribute *Exploring shape of a cushioning material*. Ask students to think about how the other structures will compare when we apply the same amount of weight on top of the plate but change the number of rings in between the plate and the table and record their predictions on the new handout you are giving them. Show **slide M**. Give students a couple of minutes to record their predictions on the handout.

14. Test the first three structures.

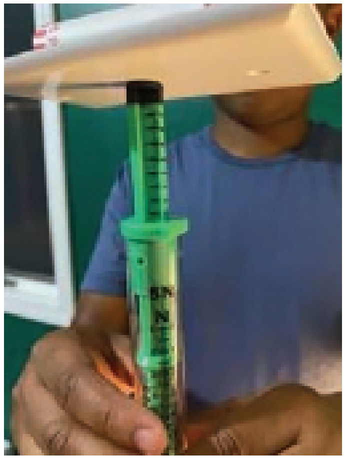
10 MIN

Materials: Other Shape Tests, *Exploring shape of a cushioning material*, science notebook

Gather around a demonstration area. Have 3 students help balance the weighted plate on top of the first three structures (1 ring, 2 rings side by side horizontally oriented, and 3 rings side by side horizontally oriented). Ask for student volunteers to help do this. Have the rest of the class gather around the demonstration area. Student volunteers should balance their weight on top of these structures, keeping it from tipping over but trying not to lift or push down on it any, just like you demonstrated. After doing this long enough for other students to record their observations (e.g., 2 minutes), ask another set of 3 volunteers to swap places with the first 3 students so that they can record observations as well.

Discuss the patterns they noticed as a class.

Suggested prompts	Sample student responses
What did you notice happening among the one-ring, two-ring, and three-ring structures?	*The more rings, the less they deformed.*
What does this tell you about the amount of force on each ring when there are two or three rings compared with when there is one ring?	*It is less.*
How much less force would there be on each ring when there are two rings instead of one?	*Half.*
How much less force would there be on each ring when there are three rings instead of one?	*A third.*



Say, *Let's use our push-pull spring scales to test this. Let's swap in a spring scale for a ring, since we know that the rings and the springs are both behaving elastically, and see how much force is registered on each spring scale.* Ask for a student volunteer to record the results on the board for each condition tested (using 1 spring scale to support the weight, using 2 spring scales to support the weight, using 3 spring scales to support the weight).

Ask for student volunteers to help hold and test the first condition. It will take at least two people to balance a weighted plate on top of a push-pull spring scale held upright. A third person can read the amount of force registered on the scale.

Do this again for two spring scales held upright under the weighted plate. This may take another person to do.

Do this again for three spring scales held upright under the weighted plate. This may take another person to do.

Give a minute for students to record their observations on their handout.

Additional Guidance

If one spring scale of the two or three used is slightly higher than the others when measurements are taken, one side of the scales may register a higher force reading than the others, but the sum total of all the forces on 2 or 3 springs scales should still add up to the total amount from the single scale test condition.

Suggested prompts	Sample student responses
How did these measurements compare to our predictions?	*This is what we predicted would happen.*
So if a collision occurred on the surface of the plate and it produced a certain amount of peak force where contact was made, how strong would the forces be below each point of contact on a three-ring structure like this?	*One-third.*
So if we could use ten rings instead of one, how much force would there be on each ring and the structure below it?	*One-tenth.*

Say, *How would this affect the amount of damage on an easily deformable object placed below it?* Students should say that it should reduce the amount of damage on it.

Place a sheet of Styrofoam on the table and under a spring scale with the plunger touching the Styrofoam. Stack all three of the weighted plates on top of the spring scale. This will make an indentation on the Styrofoam. With a fine-tip permanent marker trace the outline of where the spring-scale plunger touches the Styrofoam before removing it.

Move to an undamaged spot on the Styrofoam. Hold three spring scales together with their plungers touching the Styrofoam and place the stack of three weighted plates on top of them so all three scales are holding up the stack of plates. Trace the outline of where all three spring-scale plungers touch the Styrofoam before removing them.

Hold up or pass around the Styrofoam and ask students to describe what they notice. Students will say that there is more damage from the single spring scale than from the three.

Say, *This three-spring-scale structure provides more points of contact to push back. Because of that, the amount of contact force at each point of contact is less. In a way, we can think of the structure as spreading out the force it is pushing back with across a larger surface area. And from the Styrofoam we can see that this has an effect on the damage on a material it is in contact with. So we can see that it's not just how much peak force is applied to a material that causes it to be damaged. It's really how much peak force is being applied at a particular spot on the material. So if you can spread the amount of force being applied to more spots or over a greater area, this should result in less damage to the object those forces are being applied to. Let's see if we can use these ideas to explain what our six-ring, triangular structures do when a force is applied to them.*

15. Test the last two structures.

5 MIN

Materials: Other Shape Tests, science notebook, *Exploring shape of a cushioning material*

Carry out the last two structure tests in the demonstration area. Prepare to test the last two structures (6-ring, triangular shape). Ask for student volunteers to help do this. Student volunteers should balance their weight on top of the last two structures (6-ring, triangular shape). Ask for student volunteers to help do this. Student volunteers should balance their weight on top of the structures, keeping it from tipping over but trying not to lift or push down on it any, just like you demonstrated. After doing this for a minute as other students record their observations, ask for 2 other volunteers to swap places with the first volunteers so that they can record observations as well.

Briefly discuss what students notice.

Suggested prompts	Sample student responses
Which rings deformed less than others?	*The row of three rings deformed less than the row of two rings which deformed less than one ring.*
In each case, which objects are experiencing the strongest forces where a ring is touching, the weighted plate or the table below it?	*It depends. When the point of the triangle is touching the weighted plate, there would be stronger forces there than along the base of the triangle against the table. But when the point of the triangle is touching the table, there would be stronger forces there than along the base of the triangle against the weighted plate.*

Suggested prompt	Sample student response
So if we decided to use one of these cushioning structures to protect a collision between a falling weighted plate and the table, which of these structures would be more effective at protecting the table below it? Which would be more effective at protecting the plate above it?	*The wider part, the three rings, of the triangle should be against the surface you want to protect.*

16. Progress Tracker Update

18 MIN

Materials: science notebook, chart paper, markers

Say, *Let's summarize all of these discoveries in a Progress Tracker update as a class*. Show **slide N**. Have students prepare a 3 column entry in their Progress Tracker. You will fill in this entry together as a class.

Gather students in a Scientists Circle. Hang a piece of chart paper. Lay out a table for a whole class progress tracker entry as shown on **slide N**. Remind students that we've been working as a class on the same question about structure as the one they wrote in their Progress Tracker last time. Ask them to look back to see what that question was. Write it on the chart paper in the "Question" box and have students add it to their "Question" section for this new Progress Tracker entry.

Then ask students, *In the last lesson, what sort of testing and inspecting did we do with different cushioning materials before we started working with rings and what did we figure out from those*? Students will say in the last lesson we did a series of collision investigations to determine which reduced forces the most and inspected those materials up close.

Ask students how we figured out that the top cushioners had similar structures in terms of a lot of empty space or air within their materials to deform into. Students will say we looked at up-close and microscopic photographs of cutaways of the materials.

Add to the Progress Tracker chart paper so that it reflects these ideas. Students should add similar information to their Progress Tracker entry. It should now have something like this in it:

<table>
<tr><th>Lesson question</th><th>Source of evidence</th></tr>
<tr><td>How (and why) does the structure of a cushioning material affect the peak forces produced in a collision?</td><td>• Peak force collision tests with different materials
• Up-close and microscopic photographs of top performing materials</td></tr>
<tr><th colspan="2">What we figured out</th></tr>
<tr><td colspan="2">• Protective materials tend to have a lot of space (or air) for the solid materials to deform into, which makes these materials relatively easy to deform (with little force applied to them).</td></tr>
</table>

Ask students why we started to use rings to explore the behavior of these structures further and what we figured out at first from our increasing the space in a cushioning material through the ring collision videos.

Suggested prompts	Sample student responses
Why did we start to use rings to explore the behavior of these structures further? What about the microscopic material structure did the rings represent?	*The rings represented a common structural element in the materials, something that has a lot of space or air for the solid material to deform into.*
How did adding more rings help us visualize the effects of adding more cushioning material?	*It allowed us to see deformation occurring across the spaces within those materials.*
How did increasing the space that the cushioning material could deform into affect the total time of the collision? What did adding more rings do to the total time the collision took?	*It increased it.*
And what did this do to the peak forces produced in the collision?	*It reduced it.*
So, then, what did we discover the relationship to be between the amount of time a collision lasts and the strength of forces applied by a cushioner?	*We can change the motion of an object with materials that apply weaker forces over more time instead of using materials that apply stronger forces over less time.*

Emphasize that we also discovered that simply packing smaller and smaller spaces (or smaller rings) into a material and/or making the structure of that material more dense doesn't necessarily help it reduce peak forces, and it actually may have the opposite effect.

Add to the Progress Tracker on the chart paper so that it reflects these ideas. Students should add similar information to their Progress Tracker entry. It should now have something like this in it:

Lesson question	Source of evidence
How (and why) does the structure of a cushioning material affect the peak forces produced in a collision?	• Peak force collision tests with different materials • Up-close and microscopic photographs of top performing materials • Scaled-up ring structures attached to spring-scale carts in collision videos

What we figured out

- Protective materials tend to have a lot of space (or air) for the solid materials to deform into, which makes these materials relatively easy to deform (with little force applied to them).
- The thicker these kinds of materials are, the more they reduce peak forces because this increases the total time the collision takes.
- Making a material more densely packed with smaller and smaller spaces does not necessarily reduce peak forces. Such increased density may actually have the opposite effect.

Ask students to summarize what we figured out from the most recent test we did of 5 different ring structures. Listen for ideas like these:

- The more you can spread the peak forces out over a larger area or over more points of contact, the less force is applied to each point of contact.
- This can reduce the amount of damage on the material you are trying to protect.

Add these ideas to the Progress Tracker on the chart paper. Students should add similar information to their Progress Tracker entry. It should now have something like this in it:

Lesson question	Source of evidence
How (and why) does the structure of a cushioning material affect the peak forces produced in a collision?	• Peak force collision tests with different materials • Up-close and microscopic photographs of top performing materials • Scaled-up ring structures attached to spring-scale carts in collision videos • Testing of different-shaped structures with weights on top of them

What we figured out

- Protective materials tend to have a lot of space (or air) for the solid materials to deform into, which makes these materials relatively easy to deform (with little force applied to them).
- The thicker these kinds of materials are, the more they reduce peak forces because this increases the total time the collision takes.
- Making a material more densely packed with smaller and smaller spaces does not necessarily reduce peak forces. Such increased density may actually have the opposite effect.
- The more you can spread the peak forces out over a larger area or over more points of contact, the less force is applied to each point of contact; this can reduce the amount of damage on the object you are trying to protect.

17. Navigation

5 MIN

Materials: *Reading: Anatomy of a Bike Helmet*

Connect to a prior sports-related phenomenon and the design problem students have been working on. Remind students that they have been considering their own design problem for a few lessons now and that earlier in the unit they had looked at how some sports have a risk of concussions due to head collisions. Ask students to consider how what we summarized what we have figured out could be applied to both of these contexts. Show **slide O**. Give students 3 minutes to discuss these questions with a partner.

Assign the home learning. Show **slide P**. Distribute the reading. Emphasize that this reading will discuss the design of one type of protective headgear to prevent concussions related to collisions people can experience from riding a bike and that the information in the reading will include ideas that students will need to use on their assessment in a couple of days. Explain that assessment will come after they first revise their own designs and will involve evaluating protective headgear for preventing concussions in a different sport.

Assessment Opportunity

Building towards: 13.C Critically read a scientific text adapted for classroom use to determine how concussions can result in breaks in the axons of neurons (structure) and why this can lead to memory loss (function), how a snug fit (structure) for a helmet would affect its performance (function), and how other changes in the structure of cushioning material (in a helmet) would affect its performance (function).

What to look for: Use of structure-and-function relationships in the responses to the following questions:

- Questions 1 and 2 should include the ideas that
  - concussions can result in breaks in the axons of neurons (structure),
  - new connections between neurons is how memories are stored, and
  - breaking such structures would result in memory loss (function) which could tend to accumulate or get worse with each additional concussion.
- Question 3 should include the ideas that
  - a snug fit increases the surface area or points of contact between a helmet and the head,
  - this would spread out the forces applied to a larger section of the head,
  - this would reduce the strength of peak forces on any particular section of the head in a collision, and
  - this would improve its ability to protect the head from a concussion in a collision because the kinetic energy of the objects would be higher if there was not a snug fit.
- Questions 4 and 5 should include responses that
  - cracks or dents in cushioning material change its physical structure and
  - any changes in structure could affect how effectively it can reduce peak forces in a collision.
  - Students may mention a variety of reasons why effectiveness of the cushioning material would be reduced, such as these:
    - reducing how much it can deform,
    - changing how springy it is (its force-to-deformation ratio),
    - changing the elastic limit of the pieces that aren't broken,
    - or that the now-broken-up structure may no longer be able to spread out the force across a larger area,
    - and, in the case of the dent, reducing the number of points of contact with the head, thereby increasing the amount of peak force on the remaining points of contact.

What to do: Review this after you collect it at the start of Lesson 14 and return it to students before you start Lesson 15. Provide guidance or feedback to students in time for them to use it to prepare for the Lesson 15 assessment that uses a related protective headgear design context.

Alternate Activity

Extension: The Centers for Disease Control and Prevention (CDC) has extensive information for parents, teachers, coaches, and students about head injuries. These resources include training courses, customizable materials, public service announcements, and podcasts. (See the **Online Resources Guide** for a link to these resources. **www.coreknowledge.org/cksci-online-resources**)

Universal Design for Learning: To increase relevance for students, consider downloading and printing the following:

- concussion fact sheet for athletes
- Spanish language version
- bike helmet safety fact sheet

(See the **Online Resources Guide** for links to these resources. **www.coreknowledge.org/cksci-online-resources**) Students might also be interested in reviewing training materials, viewing the concussion-related videos, or listening to podcasts with their families.

SCIENCE LITERACY: READING COLLECTION 5

Structures and Forces

1 **Arches and Domes**
2 **Snap! That's a Great Idea After All**
3 **Getting to the Point(s)**
4 **Sneaker Mania**
5 **Sports Op-Ed**

Literacy Objectives

- ✓ Summarize key points related to structures and forces.
- ✓ Distinguish cause(s) and effect(s) related to how design features change forces.
- ✓ Determine the veracity of evidence supporting a claim.

Literacy Activities

- Read varied text selections related to the topics explored in Lessons 12–13.
- Evaluate the reading selections according to provided prompts and criteria.
- Compare and contrast information gained from reading text with information gained from class investigation.
- Complete a summarizing outline in response to the reading.

Instructional Resources

Student Reader

Collection 5

Science Literacy Student Reader, Collection 5
"Structures and Forces"

Exercise Page

EP 5

Science Literacy Exercise Page
EP 5

Prerequisite Investigations

Assign the Science Literacy reading and writing exercise *after* class completion of this lesson group:

- Lesson 12: What materials best reduce the peak forces in a collision?
- Lesson 13: How (and why) does the structure of a cushioning material affect the peak forces produced in a collision?

Standards and Dimensions

NGSS

Disciplinary Core Ideas PS2.A: Forces and Motion For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law). (MS-PS2-1); **ETS1A: Defining and Delimiting Engineering Problems** The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that is likely to limit possible solutions. (MS-ETS1-1)

Science and Engineering Practice: Obtaining, Evaluating, and Communicating Information

Crosscutting Concepts: Structure and Function; Cause and Effect

CCSS

English Language Arts

RST.6-8.2: Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions.

RST.6-8.6: Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text.

RST.6-8.10: By the end of grade 8, read and comprehend science/technical texts in the grades 6-8 text complexity band independently and proficiently.

Core Vocabulary

Core Vocabulary: Core Vocabulary terms are those that students should learn to use accurately in discussion and in written responses. During facilitation of learning, expose students repeatedly to these terms. However, these terms are not intended for isolated drill or memorization.

pressure

Language of Instruction: The Language of Instruction consists of additional terms, not considered a part of Core Vocabulary, that you should use when talking about any concepts in this exercise. Students will benefit from your modeling the use of these words without the expectation that students will use or explain the words themselves.

distribution of force
op-ed
practical limit
load
power
stress

A Glossary at the end of the Science Literacy Student Reader lists definitions for Core Vocabulary and selected Language of Instruction.

1. Plan ahead.

Exercise Page

EP 5

Determine your pacing to introduce the reading selections, check in with students on their progress, and discuss the reading content and writing exercise. If you are performing Science Literacy as a structured, weekly routine, you might implement a schedule like this:

- Monday: Designate a ten-minute period at the beginning of the week to introduce students to the assignment.
- Wednesday: Plan to touch base briefly with students in the middle of the week to answer questions about the reading, to clarify expectations about the writing exercise, and to help students stay on track.
- Friday: Set aside time at the end of the week to facilitate a discussion about the reading and the writing exercise.

2. Preview the assignment and set expectations.

(MONDAY)

- Let students know they will read independently and then complete a short writing assignment. The reading selection relates to topics they are presently exploring in their Contact Forces unit science investigations.
- The reading and writing will be completed outside of class (unless you have available class time to allocate).
- Preview the reading. Share a short summary of what students can expect.
  - *First, you will read an article about architectural structures designed to distribute stress forces from their centers downward while leaving open space beneath them.*
  - *Next, you'll read an article on bubble wrap and learn how it functions similarly to arches and domes.*
  - *Then, if you ever wanted to try lying on a bed of nails, you'll enjoy a photo essay about this phenomenon and other examples of distributing and concentrating forces.*
  - *You'll also read an article about sneaker designs and analyze an advertisement featuring an unusual design for a new sneaker.*
  - *Finally, you'll read a mock op-ed—or guest editorial—written by a doctor who has thought long and hard about brain injuries caused by sports.*
- Distribute Exercise Page 5. Preview the writing exercise. Share a summary of what students will be expected to deliver. Emphasize that Science Literacy exercises are brief. The focus is on thoughtful quality of a small product, not on the assignment being big and complex.
  - *For this assignment you will be expected to complete an outline summarizing the main ideas in this collection.*
- Remind students of helpful strategies they can employ during independent reading. Offer the following advice:
  - *The reading should take approximately 30 minutes to complete.* (Encourage students to break reading into smaller sections over multiple short sittings if their attention wanders.)
  - *A good reading strategy is to scan through the collection first to see the titles, section headers, graphics, and images to see what the selections are going to be about before fully reading.*
  - *Next, "cold read" the selections without yet thinking about the writing assignment that will follow.*
  - *Then, carefully read the Exercise Page to understand the expectations for the writing part of the assignment.*
  - *Revisit the reading selections to complete the writing exercise.*
  - *Jot down any questions for the midweek progress check in class.* (Be sure students know, though, that they are not limited to that time to ask you for clarification or answers to questions.)

3. Touch base to provide clarification and address questions.

Touch base midweek with students to make sure they are on track while working independently. You may choose to administer a midweek minute-quiz to give students a concrete reason not to postpone completing the reading until the last minute. Ask questions such as these, and have students jot answers on a half sheet of paper:

Suggested prompts	Sample student responses
Where in your body do you have a structure that functions similarly to the aqueducts of ancient Rome?	*the arches in my feet*
What do the bubbles in bubble wrap do to force applied to them?	*They distribute the force, protecting the object beneath them.*
What does pressure have to do with putting rubber or felt pads under furniture legs?	*The pads are softer and wider than the furniture legs, so they distribute the downward pressure from the weight of the furniture against the floor.*
What material does the manufacturer of Pluma Zuuma sneakers use to reduce force on runners' feet?	*goose down (feathers)*

Ask a few brief discussion questions related to the reading that will help students tie the text content to students' classroom investigations.

Suggested prompts	Sample student responses
Which of the objects or materials you read about are designed to reduce peak force in collisions?	*bubble wrap* *the springs under a turntable* *sports helmets* *sports shoulder pads* *the midsoles of sneakers*
Recall the diagrams you made in Lesson 13 showing the structure of several force-reducing materials. Which diagram would be most similar to one for the goose down in the ad for Pluma Zuuma sneakers?	*probably the one for cotton*
How did your investigations in Lesson 13 support Dr. Wallace's suggestion that thicker foam padding in helmets might improve safety?	*We found that the thicker materials are, the more they reduce peak forces.*

- Refer students to Exercise Page 5. Provide more specific guidance about expectations for students' deliverables due at the end of the week.
    - *The writing expectation for this assignment is to complete an outline focusing on structure and function related to forces and design and summarizing the selections in Collection 5.*

- *That means using language that connects specific objects with how they interact with forces.*
- *Notice that the outline framework uses complete sentences, so follow the same style for your additions.*
- *Also look at the content of the statements that are already there to infer what kind of statement would be appropriate to go along with them.*
- *The important criteria for your work are that you summarize all five readings and use language that shows your understanding of forces, stress, structures, and how they function.*

- Remind students that well-organized outlines have a hierarchy with big ideas at upper levels and details or examples at lower levels.
- Answer any questions students may have relative to the reading content or the exercise expectations.

Exercise Page

EP 5

4. Facilitate discussion.

(FRIDAY)

Facilitate class discussion about the reading collection and writing exercise. There are five selections in this collection. The first one is a photo essay about structures designed to support large amounts of weight and distribute the stress evenly throughout the structure.

Pages 44–53 **Suggested prompts**	**Sample student responses**
What is the general purpose of the first selection, "Arches and Domes"?	*It shows pictures with descriptions explaining some different structures that use arches or domes to support weight and distribute stress.*
How did you decide which examples from this reading to include in your outline?	*I chose the most interesting ones.* *I chose the most familiar ones.*
What forces are acting on an arch made of individual rocks?	*Each rock in the arch has weight and is pulled toward the ground by the force of gravity. But there are also contact forces when each rock touches another rock. These push in many different directions because of the way the rocks are stacked in the arch.*
What is the general purpose of the second selection, "Snap! That's a Great Idea After All"?	*It explains how bubble wrap works to protect delicate objects from breaking by absorbing energy and reducing the force in a collision.*
How does this selection build on what you learned in the first selection?	*The first article explained what arches and domes are and how they distribute huge weights. This article reveals that domes can also be very tiny and made of flexible materials but still have a similar function to the huge ones.*

Student Reader

Collection 5

SUPPORT—If you are using the recommended word envelope convention, check the envelope to see if it contains any words, phrases, or sentences that students need help understanding. Read key sentences aloud, and provide concise explanation.

Online Resources

Pages 44–53 Suggested prompts	Sample student responses
What do you think will happen if you place some bubble wrap on the floor, a board on top, and step down hard on the board? Why?	*I think none of the bubbles will pop because the board will help distribute the force across many bubbles.*
What is the general purpose of the third article, "Getting to the Point(s)"?	*It gives examples of how increasing or decreasing the points of contact in a collision is useful.*
This is the second photo essay in this collection. What was your approach to getting the most out of reading it?	*I always look at the photos first, try to guess why they are included, and then read the descriptions.* *I read the essay from left to right.* *I look at the photos that are most interesting first and read their descriptions. Then I glance at all the others.*
How do more or fewer points of contact affect the distribution of force?	*The more points of contact there are, the less force is applied to each contact. The fewer points of contact there are, the more force applied.*
What is the general purpose of each part of the fourth article, "Sneaker Mania"?	*The first part explains what sneaker design has to do with contact forces. The second part is a mock advertisement intended to sell a new sneaker design that uses goose down for cushioning.*
What does the kind of midsole a sprinter wears have to do with Newton's third law?	*Sprinters wear shoes with little cushioning in the midsole. This is so all the force from their legs goes into the ground and the ground then pushes back on the runner with the same force. That's what pushes their bodies forward (hopefully) to win the race.*
What is the function of a soft, cushiony sneaker sole?	*Cushioning means that there is less force against the ground and so less force from the ground to injure the joints and muscles.*
Take a look at the Spot the BS box on page 51. Would the features this product advertises really work to make a good running shoe?	*Probably not. If the material you are walking on is that soft, you would have little control over how you move.*
What is the general purpose of the fifth article, "The Collision Safety Conundrum . . . or Illusion? By Cameron Wallace, MD"?	*This is a newspaper opinion essay about preventing brain injuries in sports but is also meant to explain some of the science.*

SUPPORT—Point out to students that engineers use the concept of stress to explain how particles of different materials react to forces. Clarify that stress is calculated by dividing the amount of force by the amount of surface area it acts on, for example, 10,000 pounds per square inch (or 7,000 newtons per square centimeter).

EXTEND—Many students will not be familiar with turntables and vinyl records. For those who are interested, suggest that they look for online videos that explain how these devices work.

Pages 44–53 Suggested prompts	Sample student responses
According to the author, why are there practical limits to how much safety equipment can protect players?	*Some solutions and designs for more effective helmets and padding would just be too big or too expensive to be practical.*
How would you summarize the author's advice to readers?	*He advises that players and their parents know the risks associated with activities that can damage the brain and understand that no amount or designs of safety equipment can reduce the risk to zero.*

5. Check for understanding.

Evaluate and Provide Feedback

For Exercise 5, students should complete the provided outline framework to summarize Collection 5. A sample completed outline is shown below, with student writing in bold, but students' outlines may vary in wording and details. Look for evidence that students thought about the crosscutting concepts "Structure and Function" and "Cause and Effect" as they summarized each selection and that they were consistent in using complete sentences, proper punctuation, and accurate spelling.

Structures and Forces

I. Arches and domes are designed to support weight and distribute forces.
  A. Your feet have arches.
  B. **Suspension bridges can hang from arches.**
  C. **A dome is made of several arches.**

II. Bubble wrap has little domes to distribute weight.
  A. **When the bubbles are squeezed, energy is absorbed.**
  B. **The bubbles slow down collisions so that the force is reduced.**

III. Many points of contacts help distribute force.
  A. If the nails are close together, you can lie on a bed of nails without getting injured.
  B. A turntable has pads or feet that reduce contact.
  C. **A sports helmet has an inner layer that distributes impact forces.**
  D. **The narrow blade of an ax concentrates force, and the blunt end distributes force.**
  E. Furniture pads under the feet help distribute the force pressing on the floor.

IV. **Sneaker soles are designed for the needs of each sport.**
  A. For sprinting, spikes or cleats concentrate forces to dig into the ground.
  B. **For distance running, squishy midsoles slow collisions and reduce forces.**
  C. If shoe soles are too soft, it would be hard to produce enough force to move forward.

V. Traumatic brain injuries are related to sports.
  A. There are constraints on the design of equipment if players are to play the game as intended.
  B. **Custom-made helmets might work better but are very expensive.**
  C. Brain injuries can also happen when the head is moved quickly, even if there is no collision.

LESSON 14

How can we use our science ideas and other societal wants and needs to refine our designs?

Previous Lesson

We developed a model to represent how the structures of materials compare in the top four performers for peak force reduction. We used scaled-up versions of these structures to generate data using slow-motion video about the unobservable mechanisms at work in the system. We carried out an investigation to determine how the amount of force applied to different points of a cushioning structure is affected by the shape of that structure.

This Lesson

Putting Pieces Together

2 DAYS

We redesign our device using our science ideas and consider the implications of those changes. We share our redesigns with stakeholders to get new perspectives and feedback. We use the new stakeholder considerations to evaluate the potential design materials and use weighted considerations to analyze the choices. We reflect on the consequences of those potential changes based upon stakeholder feedback.

Next Lesson

We will evaluate other engineers' design solutions to protect cheerleaders from concussions in collisions using the science and engineering ideas we have figured out over the course of the unit. We will design our own solution and argue how it takes into consideration the criteria, constraints, and trade-offs in the proposed solution. We will revisit the DQB to take stock of the questions we have answered.

Building Toward NGSS

MS-PS2-1, MS-PS2-2, MS-PS3-1, MS-ETS1-2, MS-ETS1-3, MS-LS1-8

What Students Will Do

14.A Optimize the performance of a design by prioritizing the particular functions and properties of materials based upon stakeholder feedback to assess the relative effectiveness of the materials.

14. B Engage in a quantitative analysis using prioritized scores and consider the trade-offs of prioritizing particular uses and functions of materials to assess their relative effectiveness for the optimization of the design.

What Students Will Figure Out

- Most designs will not meet every criterion and constraint perfectly.
- When engaging in an engineering design problem, trade-offs will occur based upon stakeholder feedback.

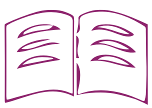
- Some stakeholder considerations will have a higher priority than other considerations.
- Every trade-off has consequences.

Lesson 14 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	**REVISIT MATERIALS TESTING RESULTS** Look back at what we have learned about material properties and structures.	A	
2	15 min	**REVISE DESIGNS** Revise designs using protective material science ideas.	B-F	*Drafting Our Protection Device Design* from Lesson 11, *Redesigning Your Protective Device*
3	5 min	**UPDATE CRITERIA AND REVISIT CONSTRAINTS** Look back at the Whole-Class Criteria and Constraints chart from Lesson 11. Refine what it means to be a protective material in criteria, and revisit constraints.		Whole-Class Criteria and Constraints chart from Lesson 11
4	10 min	**DISCUSS TRADE-OFFS USING A COMMON EXAMPLE** Look at a commonly used protective device to analyze potential trade-off decisions made by engineers and determine that even professionals have to make trade-offs.	G-H	
5	8 min	**HOME LEARNING** Go over *Stakeholder Feedback Form* and plan to receive stakeholder feedback.	I-J	*Redesigning Your Protective Device*, *Stakeholder Feedback Form*
				End of day 1
6	5 min	**SHARE FEEDBACK FROM HOME LEARNING** Learn about market research and share stakeholder feedback with a partner.	K-L	*Redesigning Your Protective Device*, *Stakeholder Feedback Form*
7	15 min	**UTILIZE A DECISION MATRIX** Use a decision matrix to compare material trade-offs for the protective device designs.	M-P	*Redesigning Your Protective Device*, *Stakeholder Feedback Form*, *Decision Matrix*, *Additional Material Considerations Matrix*
8	15 min	**USE TRADE-OFF THINKING TO ANALYZE DESIGNS** Determine primary, secondary, and tertiary rankings of criteria. Use those rankings to alter the overall score of each material.	Q-U	*Stakeholder Feedback Form*, *Decision Matrix*, *Additional Material Considerations Matrix*, calculator (optional), 2 rulers (optional)

Part	Duration	Summary	Slide	Materials
9	8 min	**CONSIDER CONSEQUENCES OF TRADE-OFFS** Consider the potential consequences of changing materials or elevating certain criteria or constraints above others based upon stakeholder feedback.	V	*Redesigning Your Protective Device, Decision Matrix*
10	2 min	**NAVIGATION** Look ahead to synthesizing information in an argument.		
				End of day 2

Lesson 14 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide**  **Student Work Pages** 	• science notebook • *Drafting Our Protection Device Design* from Lesson 11 • *Redesigning Your Protective Device* • *Stakeholder Feedback Form* • *Decision Matrix* • *Additional Material Considerations Matrix* • calculator (optional) • 2 rulers (optional)		• Whole-Class Criteria and Constraints chart from Lesson 11

Materials preparation (15 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Ensure all students have their copy of *Drafting Our Protection Device Design* from Lesson 11.

Get out and have ready to post the Whole-Class Criteria and Constraints chart from Lesson 11.

Online Resources

Lesson 14 • Where We Are Going and NOT Going

Where We Are Going

Students will engage in the design revision process to quantitatively evaluate the optimization of materials for designs. Using the revised design, students will receive feedback from stakeholders on potential considerations and trade-offs from the stakeholders' perspectives. Students will then engage in a systematic process of evaluating their materials for design solutions (ETS1.B; ETS1.C) and interpret the quantitative data produced from the ranking of stakeholder considerations based upon stakeholder feedback.

Where We Are NOT Going

While we may be prioritizing criteria and assigning them numerical scores dealing with the design trade-offs, we will not be sequencing the subproblems that need to be solved in order to systematically optimize the design. The consequences of each trade-off and prioritization will not be purposefully analyzed from a cultural standpoint, economic standpoint, or any other sources of stakeholder resistance to the solutions. Environmental impacts are listed for students to use as possible considerations in their materials selection, but no time will be spent analyzing whether the design solutions meet the stakeholders' acceptable level of social and environmental impacts associated with those considerations.

LEARNING PLAN FOR LESSON 14

1. Revisit materials testing results.

5 MIN

Materials: science notebook

Recall previous learning. Display **slide A**. Say, *Think back to last class. What did we learn about the role of shape, thickness, or properties of protective materials that we should be using in our designs?*

Give students time to turn and talk with a partner about the prompt on slide A. After a moment, ask students to share their ideas with the whole group. As students are sharing, listen for the following ideas to be discussed:

- Protective materials should have space (or air) for the solid materials to deform into.
- Protective materials should deform a lot when relatively weak contact forces are applied to them.
- The outer surface of those materials should be placed in an area where they will make contact with the damaging, colliding object.
- The inner surface of those materials should make contact with as large an area as possible on the parts of the body or object they are protecting.
- The thicker the protective material is (not always more dense), the more it will reduce peak forces.

If these ideas are not mentioned, ask students to look back at their diagrams from Lessons 12 and 13. Ask students what they notice about the materials that are contributing to a reduction in the peak forces on the object they are protecting.

Additional Guidance

The ideas about the properties of a material that provide more protection and how these properties contribute to a reduction in peak force on an object will be utilized as students revise their designs. If some students need a more-concrete version of this list, consider writing these ideas down on a piece of chart paper or whiteboard in the front of the room to serve as an idea list for the redesign and potential new selection of materials for their protective devices.

Say, *It seems like we have learned a lot about the properties and structures of protective materials! Let's see if we can apply this to optimize our designs.*

2. Revise designs.

15 MIN

Materials: *Drafting Our Protection Device Design* from Lesson 11, *Redesigning Your Protective Device*

Introduce *Redesigning Your Protective Device*. Display **slide B**. Instruct students to get out their handout *Drafting Our Protection Device Design* from Lesson 11. Explain that students will get a chance at revising their old design from Lesson 11 to reflect the current understanding of materials and how they help reduce peak forces in a collision. Using a fresh, new handout to record their protective device redesign will allow students to keep a record of their first iteration of their designs as they draft their new ideas. Distribute *Redesigning Your Protective Device* to students and go over it with them. Begin by pointing out the box where students will be drafting their redesigned protective devices. Make sure that students know they will be redrawing their ideas in this box, using their old designs on *Drafting Our Protection Device Design* as a starting point. Direct students to then look at the table on the next page. Explain that this table will walk students through considering what changes they are making and why. Column 1 asks students to list the changes that are being made, column 2 asks students to give their reasoning for the changes based upon their science ideas, and column 3 asks students to think about what effects those changes will have upon their system. Because this chart is new, tell students that we will do an example together based upon a design to protect a car side mirror in a parking lot.

Display **slide C**. Point out that the chart on the slide is a copy of the chart on their handouts.

Say, *Imagine that I had designed a protective device to put onto the side mirrors of my car when I am parked in a parking lot to avoid scratches and bumps. Originally I had made a design that was a box of wood because I thought it would be really sturdy, but I didn't think about the energy transferring through the wood. Now I have changed my design to be made of the same foam as earplugs.*

Display **slide D**. Point out to students how the change is documented in the first column.

Say, *Now I need to think about how I can justify this change using my science ideas. I made the change from wood to foam because foam deforms more and can be shaped to spread the impact out over a larger area when it is being deformed. The wood would get bumped and then would just bump right back into my mirror!*

Display **slide E**. Point out to students how this rationale is documented in the second column of the chart.

Say, *Finally, I have to think about the change on the overall structure of the device. There are positive and negative effects that would happen if I use foam as my main material instead of wood. I like the idea of foam better, but I think that making it out of foam will have an effect on how durable it is. I decreased how durable my design is since the wood would definitely hold up better over time. Also, foam just can't be nailed together like wood. Because it needs special glue or something to create, it will also be a lot harder or take more time to create and sell. On the other hand, the foam will be easier to store since it can deform and probably fit under a seat in the car.*

Display **slide F**. Direct students to look at the documentation of these ideas in the third column.

Tell students that they will be given time to work on this redesign. Explain that if students have made more than 3 major changes to their designs to focus the chart on the biggest changes made based upon their science ideas. Give students 10 minutes to work on their own to complete *Redesigning Your Protective Device*.

3. Update criteria and revisit constraints.

5 MIN

Materials: Whole-Class Criteria and Constraints chart from Lesson 11

Bring the class back together. Display the Whole-Class Criteria and Constraints chart from Lesson 11. Recap that up until this point our designs have focused on what materials will best help our designs protect our objects. We have spent some time learning about the materials' properties and thinking about how best to meet those criteria. Point out that while we have done a great job addressing what we mean by good shapes and protective materials and incorporating our science ideas into our design, we also said that we have constraints to consider.

Say, *When we started to design our devices, we created a Criteria and Constraints chart. Other than our criteria, what else did we say we needed to consider as a class?*

Allow students time to share out the items in the "Constraints" column. If students would like to add more constraints than currently listed on the chart, add those to the chart at this time.

Continue discussing the constraints list with students. Determine that different devices will have different constraints depending on the use of the object being protected and that all constraints may not be met perfectly for the practical use of the device. Example prompts and responses are located in the following table.

Suggested prompts	Sample student responses
This is a long list of constraints. Would every constraint apply to everyone's individual protective device design?	*No.*
Interesting. Let's look at our list. Which constraints may be design-specific?	*(Accept all valid responses.)* *(Students may mention ideas like designs needing to be waterproof or having size constraints.)*
OK, let's think about each of the constraints that do apply to your devices. Looking at the constraints that are important to your device, did your device meet those constraints perfectly?	*My device met most of the constraints.* *My device met the criteria, but I had to prioritize my constraints.* *(The majority of students will say that their device did not meet every single criterion and constraint.)*
So what I am hearing is that our designs don't seem to meet all the criteria and constraints, but we tried to make the best decisions possible for our devices. Do you think that other protective device designers have to make decisions about what to prioritize as well?	*Yeah, different devices have different considerations, and some have too many considerations to make everyone happy.* *The number of and reasoning behind different considerations might make it hard for a single design to meet the criteria and constraints perfectly.* *Some people may have conflicting criteria and constraints, so both can't be met perfectly. There has to be some compromise.*

Say, *It's interesting that device designers seem to have to make the best decisions based upon the need and considerations of those that the device affects. It also sounds like some considerations are more important than others in most designs, and sometimes compromises need to be made. Do you think that a professionally designed item would also have some of these compromises in its design? Let's take a look at a common protection device together to see if actual engineers have had to make the same kinds of decisions.*

4. Discuss trade-offs using a common example.

10 MIN

Materials: None

Discuss trade-offs with knee pads. Display **slide G**. Ask students to turn and talk about the questions on slide G.

- What are some constraints that would apply to this protective device?
- Are there any constraints that the design would have that are more important than others?

Ask students to share their ideas with the class. Students should identify the constraints of size, cost, type of material used, shape, ease of use, reusability, and others as considerations that a designer would have to keep in mind when creating this device.

Discuss trade-offs. Remind students that we learned about trade-offs in the *Tsunami Unit* and *Homemade Heater Unit*. *Trade-offs* are when criteria or constraints have to be weighed against each other to make an informed decision. When designers of these devices are weighing the options and the relative importance of criteria or constraints, they are making trade-offs. Ask students about the trade-offs made during the designing of the kneepad. Example prompts and responses are located in the following table.

Additional Guidance

The term *trade-off* was utilized in *Tsunami Unit* to explain why students did not agree on the best choice tsunami-mitigation design. Trade-off thinking was discussed as weighing criteria and constraints against each other, and then those were used to determine which were more important to make an informed decision about what structure to utilize in a tsunami-mitigation design problem. The effects that these trade-offs had on other criteria, systems, or groups were also explored. Trade-offs were also explored in the creation of a device to heat an MRE in *Homemade Heater Unit*. In that unit, trade-offs were weighed to determine acceptable ratios of materials and their heating abilities. If students have not had exposure to the *Tsunami Unit* or *Homemade Heater Unit*, spend some time discussing how trade-offs can affect other aspects of the system, stakeholders, and other groups. The term *trade-off* can be added to the Word Wall if needed.

Suggested prompts	Sample student responses
Looking at this knee pad device, what do you think are some criteria and constraints that would apply to this device, both from a science idea perspective and the perspective of someone who is going to use it?	*I think that the device would have the criterion of being protective.* *The device would need to be comfortable.* *I would need to be able to move easily with the device on, so the device can't come out from my knee too far.* *It needs to come on and off easily when I am sweaty.* *It would need to be affordable.* *I think the device can't be too long. That might affect my ability to move my leg if it is too long.* *It needs to look cool and match the team colors.* *It definitely needs to be reusable and hold up to damage.*
We have mentioned a lot of things that a designer would have to consider when creating this protective device. What might be a trade-off a designer of a knee pad would have to consider regarding the size of the pad and the safety of the player?	*The bigger the size of the knee pad, the more potential for protection there is for the player, but the larger the knee pad, the less mobility or movement the player would have.*
So you're saying someone had to make a choice, or informed decision, about what feature was worth more in a design, even though size and safety are both important to the design?	*Yeah, they had to look at the design and think about what would actually work when playing the game.*
Do you see any other trade-offs that were made, and why do you think they made those trade-offs?	*The design could have a much chunkier shape, but then it wouldn't look as good, so they had to think about what people would buy versus what is safe. I don't think people would buy it if it were chunky.* *They could have added more materials, but then maybe it would weigh too much for it to stay up on a kneecap area during the game. They had to limit the amount of materials used so the device is actually usable.* *I bet they could have used a better protective material on the inside around the kneecap, but when you are sweaty it may slide up or down. Keeping it in place is probably more important than a small boost in safety.* *(Accept all other trade-off-related responses.)*

Say, *It seems that these trade-offs you are mentioning are very purposeful. It appears the designer really thought about the effects each change would have on the device and what would be important for safety but also user friendly at the same time. They had to make choices that they felt optimized the design but stayed within the limits of the device.*

Consider sources of feedback. Project **slide H.** Have students turn and talk with a partner about the prompts on the slide.

- If we were to think about trade-offs for our devices, who would we need to consult to make sure we were making an informed decision about what was important?
- Why would we need to consult and consider the feedback of others in the first place?

Ask students to share their ideas about the first question with the class. Students should identify the following people:

- the people who know the science behind the design
- those who will use the design
- those who will benefit from the design
- those who are impacted by the design

Ask students why we would need to consider feedback from others in the first place. Students should respond that without their feedback it may not meet their needs and people may not buy the design.

Say, *OK. We have done a great job learning about the science behind our designs, but if we are going to make our devices better, we need input from people who will use the designs, benefit from the designs, or be impacted by the designs. This group of people is referred to as* stakeholders. *We need to consult at least some of our stakeholders*.

Remind students that in the *Tsunami Unit* we learned about stakeholders. *Stakeholders* are the people who have interest in or concern for something. As we redesign our protective devices, our stakeholders will be the ones who would eventually use and/or purchase the devices. We could make the safest design in the world, but if our stakeholders would not purchase it or use it, then the design is useless. Stakeholder feedback will be needed and very important to the design of our protective devices.

5. Home Learning

8 MIN

Materials: *Redesigning Your Protective Device, Stakeholder Feedback Form*

Prepare stakeholder feedback form. Explain to students that we have a form to use that will help us get feedback from stakeholders. The form is set up to ask the stakeholder questions based upon the design type and will help get targeted feedback to help optimize the design.

Explain to students that sometimes when we think about giving feedback on designs, we limit our thinking to just critiquing a specific design and the choices made in that specific design instead of considering the possibilities of what could be created if a totally new, never-before-seen design was being made. To make sure we don't limit our feedback, we will first need to get ideas from stakeholders about our potential designs without the stakeholders being influenced by our designs.

*** Attending to Equity**
Universal Design for Learning: Engineers routinely engage stakeholders in the feedback process. As students work as engineers they will engage in these same processes to refine their designs. When students utilize the stakeholders in their communities to refine a design of their choosing, authentic *engagement* in the

Tell students that this can be done by either discussing designs that are already in use or by asking stakeholders generally what they would like to see in that kind of protective device design. This way students will be able to figure out what considerations are truly important to them without stakeholders feeling that they are being critical of the student's design. After that, we can then introduce our design and get more-targeted feedback on our design and trade-offs.

Distribute *Stakeholder Feedback Form*. Start by pointing out the two different parts to the handout. Part 1 is all about preparing and organizing our ideas to share with our stakeholders. Part 2 will be where we record the feedback from our stakeholders. Tell students that we will be going through part 1 together, and part 2 will be home learning.

Introduce the decision tree. Project **slide I.** Explain that step 1 will help us know what to say to our stakeholders depending on our type of device. Walk through the decision tree in step 1, pointing out the two different columns on the slide that correspond with the columns on the handout.

Say, *Look at your design on Redesigning Your Protective Device. If you have designed a protective device that you think improves upon existing designs, like making an improved cell phone case, you will use the prompts in the first column. If you are creating a novel design for an object and there is no current protective device already available, use the prompts in column two. Let's use some time right now to complete the column that applies to your design.*

Give students time to complete the column that is applicable to their design. Circulate and verify that students are using the correct column for their design.

Explain step 2. Project **slide J**. Next, direct students to step 2 on their handout. Explain that the table will help students think about their design trade-offs and organize them so they can more-easily share their design decisions with their stakeholder. In the first column students will list the trade-offs used in their design. In the second column, students will give the rationale for the trade-off choices. Explain that the rationale is important to share with the stakeholder since a quick viewing of the device design may not allow the stakeholder time to consider the impact of trade-offs associated with certain design decisions.

Go over the home learning with students. After explaining the table, move on to the home learning portion of the handout. Point out that step 3 is going to have students use the script identified in step 1 when discussing potential designs with their stakeholder. In part 2 students will get ideas from the stakeholders before sharing their design. Tell students that it is OK if they want to ask more than one stakeholder, and if they run out of room they can write on an additional piece of paper or in the margins of this home learning handout.

task increases as students see themselves, their decisions, and the effects that they can have on their communities. This will help students *express* solutions that are more relevant for their personal stakeholders and therefore ultimately more optimized for the problem they are trying to solve.

Additional Guidance

This feedback will be important to obtain before the next class period. Due to dynamics outside of the school day, it may be important to provide some time during class for students to get feedback from others. If students finish steps 1-2 early during class, it may benefit them to start receiving feedback from another classmate. Remind students that feedback can come from any type of stakeholder (those impacted by the design, those that use the design, and those that benefit from the design). Other teachers, support staff, or administration can also be stakeholders for some devices. If students come to the next class period without the feedback completed, have students quickly get feedback from any available stakeholder.

On step 4, explain that students will use the trade-off table they will complete in step 2. They will share their decisions with their stakeholder and ask their stakeholder if they have any additional considerations or ideas. They will document those ideas in the table below step 4.

Finally, step 5 is asking the stakeholder to do a review of the product. Tell students that it is OK to give the paper to the stakeholder for them to record their review. Students should make sure to let the stakeholder know that it is important to be honest so that the review can be used to optimize the design. Remind students that stakeholders are anyone impacted by the design, which means stakeholders can be other teachers, students, neighbors, friends, or even siblings or other family members.

Allow students to work on the trade-offs table in step 2 until the end of the class period. As students are preparing to leave class, remind them to take home both *Redesigning Your Protective Device* and *Stakeholder Feedback Form* to get feedback from their stakeholders. They will collect feedback on their design from a stakeholder as their home learning, and the feedback will be used in class next time to consider design revisions.*

End of day 1

6. Share feedback from home learning.

5 MIN

Materials: *Redesigning Your Protective Device*, *Stakeholder Feedback Form*

Draw parallels to market research. Project **slide K**. Explain to students that during their home learning they engaged in something real engineers do to get feedback from stakeholders. This is called *market research*. Companies and designers use different methods such as conducting focus groups, reviewing stakeholder thoughts on existing designs, analyzing stakeholder data from existing designs, and conducting large polls. But they also go and ask the consumers directly, just as students did during their home learning task. Explain that engineers also collaborate to create an optimal design, and the more stakeholder feedback that is received, the better the potential the design has to meet the needs of the stakeholders as a whole. Because of this, we are going to have an opportunity to share our feedback from our stakeholders with someone else in our class.

Share stakeholder feedback. Project **slide L**. Tell students that they can use the prompts on slide L to share their feedback from stakeholders with their partner. If their partner shares some good feedback or a trade-off that they think is important, they should add it to their handout.

Circulate as students are sharing the feedback they received from stakeholders on their devices. Listen to what trade-offs and feedback students were given by stakeholders and what trade-offs students would consider in the revision of their designs. Bring the class back together after the partners share to discuss the trade-offs and feedback shared by the stakeholders.

Say, *I heard a lot of different trade-offs that were mentioned by stakeholders, like ____, ____, and ____. It sounds like some of these trade-offs might be useful in our designs, while other pieces of feedback may not be as useful. Now that we have had a chance to talk to our stakeholders, let's think about the things our stakeholders are prioritizing and determine if those changes would actually help to optimize the design.*

7. Utilize a decision matrix.

15 MIN

Materials: *Redesigning Your Protective Device*, *Stakeholder Feedback Form*, *Decision Matrix*, *Additional Material Considerations Matrix*

Say, *Some of our trade-offs or suggestions mentioned by our stakeholders seemed to be practical, like it has to hold up to repeated uses or that it needs to be a certain size. Others, like how the design looks, should be considered too, but we may not think they are as important. We have to remember that to a stakeholder all of their feedback is important, so we need to consider all the feedback and trade-offs. When we think of potential stakeholder criteria such as durability, reusability, environmental friendliness, and protectiveness of our device, we are really evaluating the use of the materials that the design is constructed with.*

Explain to students that before engineers build their designs, they take into account the materials. Designing and redesigning prototypes can get expensive, so engineers try to get the majority of the issues resolved on paper before building the prototype. Tell students that in order to make sure we are using the right materials that align with the stakeholders' feedback, we will get a chance to use a matrix to assess how well each material will potentially work for our designs.*

Distribute *Decision Matrix*. Project **slide M**. Pass out a copy of *Decision Matrix* to each student. Explain that students will be looking at the materials and considering how well they meet the stakeholder considerations and our science ideas. Students should remember using a matrix to evaluate choices in designs in the *Cup Design Unit*, *Tsunami Unit*, and *Homemade Heater Unit*. Tell students that we will add to our matrix just like we did in those units and focus on our material choices as we evaluate the trade-offs of each design. Tell students that just like in prior units, we will use the 1-to-5 scale to rate how well each material meets the considerations of the stakeholders, with 5 being the best and 1 being the worst.

Begin by having students look back at their designs on *Redesigning Your Protective Device* and their feedback on *Stakeholder Feedback Form* and think about the different materials they are considering for their device. Point out the "Material choice" column on their blank matrix. Have students list these potential materials in that first column. Tell students that we will get to compare and evaluate these materials once we determine our important considerations that we want to use to rate these materials against.

Say, *We will be starting with a blank matrix since we all have different objects we are protecting. Part of the matrix will have to be completed on your own, but there are criteria that we can all agree upon. Let's record that together. What are those criteria?*

Elicit responses from students. Students should say that one criterion is that the device needs to be made of materials that are good at protecting our objects. Ask students how we know that a material is protective. Students should respond that the material would reduce peak forces on the object it is protecting. Since students have already spent time exploring and naming the properties a material's structure has to have to make it protective, explain to them that we will just use the criterion of force reduction on our matrix. Direct students add this to our matrix by writing "force reduction" in the red space under column head "Consideration #1".

Direct students to think about other considerations that they or their stakeholders thought were important. Ask students to share 2-3 more examples and show them on the slide where those considerations would be added to the matrix. Have students think about considerations specific for their designs and list them under the other "Consideration" columns on their own handouts.

*** Supporting Students in Developing and Using Structure and Function**

In previous lessons, students have worked to uncover the properties of the small and microscopic structures of protective materials that aid in the reduction of peak forces on objects. In this lesson, students shift from thinking about the structure and function of the individual parts of the material to how well the material structure fits the design considerations based upon those properties for the use of the material within the overall system of our protective device design.

Say, *Now that we have thought a bit about what we want to evaluate for our material choices, we need to start assigning ratings to how well potential design materials meet our needs. Luckily, scientists and engineers have done many tests on the materials we have analyzed so far, and we were able to get some of those data to use in our redesign.*

Establish reliability of data. Project **slide N**. Explain to students that data for commonly used packaging materials were assembled for our use by the Michigan State University School of Packaging. This specific school at Michigan State University is focused on studying (and teaching) all aspects of packaging and packing materials. Researchers who work there took our list of common materials from Lesson 11 and ran the same amount of each material through a Life Cycle Analysis (LCA) program that is used to look at completed package designs. They were able to assess the environmental impacts of each material. The university also used some of their preexisting data on the same amounts of materials to rate each material in the other categories shown.

Explain categories. Go over each category with students. Tell students that if they find a relevant category they should add it to their matrix as a new consideration. The ratings are given as a comparison from one material to another. Below is a description of each category:

- Force reduction- how well the material reduces force on an object that it is protecting (The better the score is, the better the device does at reducing peak forces.)
- Reusable- It can collide with other objects again and again and still be reused.
- Robust- how well the device will work to protect heavy objects in a collision
- Recyclable- how easy it is to recycle the material based upon availability of recycling sites for that material
- Biodegradable- how well the material will biodegrade when thrown out
- Low material cost- how cheap the material is for the same size sample
- Low cost to work with the material in a design- how inexpensive it is to pay a worker to use that material to create a design solution
- Water used for production- how much water goes into the creation of that material
- Does not contribute to climate change- how small of an impact the creation of the material has on climate change

Ask students to copy any relevant considerations that they would like to use from this list onto their matrix.

Present data for student analysis. Project **slide O**. Distribute *Additional Material Considerations Matrix* to students. Show students the 5-point rating scale that has been used, which matches rating scales used in previous units. Remind students once again that to have a rating of 5 means that it works well with that consideration. A rating of 1 means that it does not work well with that consideration.

Transfer data to the Decision Matrix. Project **slide P**. Tell students that in a moment they will transfer only the data that apply to their materials and design from *Additional Material Considerations Matrix* to *Decision Matrix*. Remind students that the ratings were done comparatively, so the materials were compared to each other to create those ratings. *If* students are going to consider materials *not* on *Additional Material Considerations Matrix*, have them think about how well the material would do compared to the others for each consideration and assign it a fair rating on the scale of 1–5. Tell students they can ask a partner to help verify any newly developed ratings as they are transferring the data to the *Decision Matrix*. Allow students time to transfer and develop ratings.

8. Use trade-off thinking to analyze designs.

15 MIN

Materials: *Stakeholder Feedback Form*, *Decision Matrix*, *Additional Material Considerations Matrix*, calculator (optional), 2 rulers (optional)

Establish a need for ranking criteria. Once students have had a chance to fill in the data on the matrix, bring them back together as a class. Project **slide Q**. Have students turn and talk with a partner about the question on the slide.

- Use your "Total points" column to total up the ratings for your particular design.
- If we were to look at the ratings and select the best material based upon which material has the highest overall rating, would that be the best material for the design? Why or why not?

Say, *OK, now we have all our important data and considerations rated together on one page. If we were to just go across the chart and look at the material with the highest total points, would that material be the best for the design? Why or why not?*

Review primary and secondary considerations. Allow students to respond. Students will mention that while some materials are rated lower in force reduction, the other considerations bring up the overall score. Remind students that in *Tsunami Unit* we determined that some considerations were more important than others. We reviewed our criteria and constraints and labeled the most important considerations as primary and the others as secondary.

Ask students, *If we were to establish a consideration across all materials that was the most important, what would it be?*

Students should respond that the primary goal of reducing peak forces on the object would be the primary consideration. Have all students put the letter "P" for primary above the "Force reduction" column.

Ask students if there are other considerations that are still important to the functionality of the device, but may not be a primary consideration. Allow students to give a couple of examples of these considerations, such as the consideration of reusability.

Remind students that in the past we have used the secondary consideration designation for these criteria and constraints. Explain to students that we will label the consideration columns that fall into this category with the letter "S" as secondary considerations.

Introduce *tertiary considerations*. Project **slide R**. Say, *Since we are working with stakeholder input, all of the input is valuable. But, we also know that some input is more valuable than others. Some stakeholder considerations are based around the actual function of the device, and some may be superficial. Because of this, we will be adding a third level of classification called* tertiary considerations.

Explain that this third level of classification falls below the rank of secondary considerations. It will be the least important of our considerations when working with a material. Tell students that now that we have an established prioritization system, we will start assigning our considerations as primary, secondary, or tertiary.

Determine primary criteria. Ask students to look at their charts on *Decision Matrix* and start by determining what should be considered primary criteria and label the space above these columns with the letter "P". Remind students that the primary considerations are the most important items to the stakeholders.

Determine secondary and tertiary criteria. After establishing primary considerations, students should look at the remaining considerations and determine if they are of more or less importance. If any considerations are deemed

*** Supporting Students in Engaging in Using Mathematical and Computational Thinking**

While students have had experience prioritizing criteria and constraints in the *Tsunami Unit* and *Homemade Heater Unit*, they had not quantitatively considered the impacts of the prioritization of these considerations. In this lesson, students prioritize stakeholder considerations and assign numerical rates to the different consideration priority levels in an effort to quantify the data. Multiplication is used to weight higher-ranking considerations against other, lower-ranking considerations. By comparing the new total scores for each material, students are able to get a picture of which material best meets the needs of the design. As students progress into the high school SEPs, they may modify this thinking with *gating criteria*, or criteria that must be met in order for the design to be evaluated further, for each material before it is evaluated quantitatively.

*** Attending to Equity**

Some students may need assistance with the multiplication of a long set of numbers. Offer these students the use of a calculator that displays the multistep equation as it is added to be of a higher importance, but not quite primary criteria, students should label the space above these secondary criteria with the letter "S". All other criteria should be labeled tertiary criteria with the letter "T" in the space above their corresponding columns.

to the calculator. Remind these students to use parentheses where appropriate. Some students may benefit from the use of a ruler to keep track of numbers on a line or two rulers to block out unneeded data for the row and "chunk" only the needed information together for each material.

Assessment Opportunity

Building towards: 14.A Optimize the performance of a design by prioritizing the particular functions and properties of materials based upon stakeholder feedback to assess the relative effectiveness of the materials.

What to look/listen for: Look for students to appropriately assign primary, secondary, and tertiary criteria based on stakeholder feedback from *Decision Matrix*.

What to do

- Establishing primary considerations: If students are struggling with determining if they should assign a primary label to a consideration, ask them if the stakeholder would consider not meeting that consideration a "deal breaker" when deciding if they should purchase the device. Also ask students if not having this consideration completely met would affect the device bad enough that it would become unusable. If the consideration is that important, it should be labeled as a primary consideration.
- Establishing secondary considerations: Ask students if they have any considerations that seem very important to stakeholders, but the design would still function without meeting the consideration. If this is the case for any consideration, then it is labeled a secondary consideration.
- Establishing tertiary considerations: Ask students if they have any considerations that might vary a lot in importance from one stakeholder to another or considerations that seem superficial. If any considerations fall into this category, students should label these as tertiary considerations.

Check criteria rankings with a partner. Display **slide S**. Ask students to share their labeling of primary, secondary, and tertiary criteria with a partner. Tell students that engineers also do this, and it is referred to as checking for interrater reliability. Students should give their partner feedback orally using the prompts on slide S. Students should adjust their rankings as needed based upon the feedback from their partner.

Compare overall scores of materials. Alter point values based upon rankings. Discuss ways to elevate the primary criteria and constraints with students. Example prompts and responses are below.

Suggested prompts	Sample student responses
Let's look back at our materials. We have ranked them as primary, secondary, and tertiary, but if we add up the total values, did the overall score change?	*Mathematically, each material still has the same value.*
Why could this be problematic?	*We know certain criteria are worth more than others. We should have a way to show that they are worth more.*
How do you think that we can alter the scale so that the items we think are the most important stand out?	*Maybe we can make them worth more overall points.*

Suggested prompts	Sample student responses
OK. Engineers do this too using a process where they weigh different considerations based on importance. We can do that by weighting our scores. Let's start with the most important stakeholder concerns. The primary considerations. How much do you think these should be worth?	*They should be worth more than the others.* *Since we have primary, secondary, and tertiary, maybe they should be worth three times as much as the rest.*
So since we have three levels, the primary considerations should be worth three times as much?	*Yes.* *Yeah! That makes sense.*
So what should the secondary concerns be worth?	*They should be worth two times as much since they are secondary.*
This means that the tertiary concerns can just stay the same value, since the primary and secondary are weighted more than them. Are we OK with that?	*Yes.*

Project **slide T**. Allow students time to do the multiplication involved with weighting the scores and then the addition in totalling up the new material score.** If some students struggle with how to do this multiplication, use the example on slide T to walk them through this process of weighting the criteria, multiplying based upon the rating, and then adding up the total new points for each material.

Reflect on weighted scores. Project **slide U**. Have students compare pre vs. post weighted scores with a partner using the prompts on slide U. After students have had a chance to share, bring the class back together. Ask students if they believe these scores are more reliable. Some students may respond that these scores are more reflective of what the design needs to do, and some will be able to see a change in the highest rated material for their design. Others may point out that there are some criteria that should be "gating" criteria, that if they do not meet that criteria they should be automatically eliminated (they don't make it through the gate to the next round of consideration). Verify for students that this process involves a lot of trade-offs from one aspect to another, and all criteria may not be met perfectly. But, by looking at the different considerations from a stakeholder's point of view we learn how to make the designs work for the consumers.

9. Consider consequences of trade-offs. 8 MIN

Materials: science notebook, *Redesigning Your Protective Device*, *Decision Matrix*

Consider design optimization consequences. Say, *Let's think about some of these trade-offs we are now considering with the use of certain materials. It is clear from our different ratings that certain changes and decisions have unintended consequences. By elevating certain criteria, we may be discounting something else important to the stakeholder, or by only looking at the total scores we may miss something else that is more important to the overall rankings. Let's spend some time reflecting on these choices that we would like to make to optimize our designs.*

Display **slide V**. Remind students that in the *Homemade Heater Unit* they worked with identifying what consequences their choices would have on the design and how that might affect stakeholders. Tell students they will consider the implications of trade-offs and prioritizing of considerations.

Instruct students to create the chart on the slide on the next clean page in their notebook. Explain that in the first column students will write their different decisions regarding their materials and design, according to their most recent matrix exercise. In the second column, students will consider what effects these changes will have on other stakeholder concerns or input, and in the third column students will consider what effects this design decision would have on the overall design of the device. Give students time to complete this trade-off and prioritization reflection on their own.

Assessment Opportunity

Building towards: 14. B Engage in an analysis to consider the trade-offs of prioritizing particular uses and functions of materials to assess their relative effectiveness for the optimization of the design.

What to look/listen for: Students should list the design decisions they have made according to their redesign table and decision matrix and explain the potential effects (which can be positive and negative) that each design decision will specifically have on stakeholder concerns or considerations. Students also consider what effect the decision will have on the overall design of the device and explain how those decisions impact the performance of the design (which can be positive and negative).

What to do

- Column 1: If students need help listing their design decisions, direct them back to *Redesigning Your Protective Device*. Ask students what changes were made to the design and have them list those changes in column 1. Also have students look back at their decision matrix. Ask students what decisions they made to assign primary, secondary, and tertiary criteria. If they prioritized one criterion over another, have them add that design decision to column 1.
- Column 2: Direct students to look at their list of design decisions in column 1. Ask students, *How would this decision affect the people who use or rely on this device? Would those people have any additional concerns because of this choice?* Ask students these two questions about each design decision listed.
- Column 3: Direct students to look at column 1 one last time and think about how these decisions impacted the actual physical structure of the device. Ask students what would happen to the device if they made a different decision, used a different material, or prioritized something else instead of what they had chosen. Tell students to write those potential outcomes of different decisions on their device structures in this third column.

10. Navigation

2 MIN

Materials: None

Say, *We have done a lot of work to ensure we are making informed choices for our designs. Now that we have some great ideas for how to improve our designs for our stakeholders, let's take some time at the start of our next lesson to synthesize all the data and trade-offs. We can then craft an argument to support our design for marketing purposes. We will also use our science ideas to evaluate some new protective designs!*

LESSON 15

How can we use what we figured out to evaluate another engineer's design?

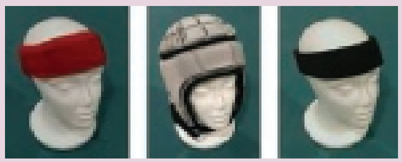
Previous Lesson

We redesigned our device using our science ideas and considered the implications of those changes. We shared our redesigns with stakeholders to get feedback. We used the feedback to evaluate the potential design materials and used weighted considerations to analyze the choices. We reflected on the consequences of those potential changes based upon stakeholder feedback.

This Lesson

Putting Pieces Together

2 DAYS



We evaluate other engineers' design solutions to protect cheerleaders from concussions in collisions using the science and engineering ideas we have figured out over the course of the unit. We design our own solution and argue how it takes into consideration the criteria, constraints, and trade-offs in the proposed solution. We revisit the DQB to take stock of the questions we have answered.

Next Lesson

In an optional extension lesson, we will develop a presentation to share with potential investors about the merits of our design. We will have the option to create a scale prototype and test our designs with additional options to add visual aids to our presentations. We will present our design ideas to investors.

Building Toward NGSS

MS-PS2-1, MS-PS2-2, MS-PS3-1, MS-ETS1-2, MS-ETS1-3, MS-LS1-8

What Students Will Do

15.A Develop and use a series of models to represent (a) the relative strength of the forces (change and stability) being applied to three different objects and subsystems in contact in a collision, (b) in each case what interaction (cause) is producing this force (effect) on the object, and (c) the direction of these forces in three different free body diagrams and use the ideas from these models to support or refute an argument for the effect on peak forces on heads during a collision.

15.B Construct an explanation for why a design solution will optimize performance, including the prioritized criteria, constraints brought from stakeholders, and trade-offs made when revising the design to meet criteria.

15.C Design a solution to a problem to reduce the damage to an object in a collision (by reducing peak forces) by considering the properties of different materials and shapes being used to serve particular functions.

What Students Will Figure Out

- Criteria inform the overall design solutions. Different criteria and trade-off choices will lead to different designs.
- All criteria cannot be perfectly met all the time for all designs; many times design solutions take into consideration trade-offs.
- We can answer many of our Driving Question Board questions.

Lesson 15 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	3 min	**INTRODUCE THE DESIGN PITCH** Review the components and materials needed to put together a proposal for student designs.	A	
2	20 min	**CONSTRUCT INDIVIDUAL DESIGN PITCH** Use *Final Design Proposal* to outline a product proposal pitch for potential investors.	B	*Redesigning Your Protective Device, Stakeholder Feedback Form, Decision Matrix, Final Design Proposal*
3	20 min	**PART 1 TRANSFER TASK** Complete *Part 1: Cheerleading Headgear Assessment* independently.	C	*Part 1: Cheerleading Headgear Assessment*, computer, projector, video (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)
4	2 min	**NAVIGATION** Collect students' transfer tasks.		*Part 1: Cheerleading Headgear Assessment*
				End of day 1
5	25 min	**PART 2 TRANSFER TASK**	D	*Part 2: Cheerleading Headgear Assessment*, 10 mini index tab flags of one color (e.g. green) and 10 of another color (e.g. yellow)
6	10 min	**REVISIT THE DRIVING QUESTION BOARD (DQB)** Revisit the DQB with the whole class and take stock of all the questions we've now answered.	E	10 mini index tab flags of one color (e.g. green) and 10 of another color (e.g. yellow), optional: chart paper, markers
7	8 min	**QUICK WRITE: REFLECT ON OUR EXPERIENCES** Students discuss what was challenging and rewarding about this unit.	F	
				End of day 2

Lesson 15 • Materials List

	per student	per group	per class
Lesson materials Student Procedure Guide Student Work Pages	• science notebook • *Redesigning Your Protective Device* • *Stakeholder Feedback Form* • *Decision Matrix* • *Final Design Proposal* • *Part 1: Cheerleading Headgear Assessment* • *Part 2: Cheerleading Headgear Assessment* • 10 mini index tab flags of one color (e.g. green) and 10 of another color (e.g. yellow)		• computer • projector • video (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**) • optional: chart paper • markers

Materials preparation (15 minutes)

Online Resources

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Prior to class be sure the video link works for part 1 of the transfer task. (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**) This will be played for the class as a whole; students do not need to watch individually.

For day 2, you will need 10 mini index tab flags of one color (e.g. green) and 10 of another color (e.g. yellow) for each student to use when revisiting the DQB. As an alternative to this, you may wish to make an updated copy of *Reviewing Our Driving Question Board* for students to use individually before revisiting the DQB. These are reusable, so collect them at the end of one class to reuse in the next class and to save to use across years.

Lesson 15 • Where We Are Going and NOT Going

Where We Are Going

This lesson is the formal end of the unit.

Where We Are NOT Going

The next lesson (Lesson 16) is an optional extension for use after this end of the unit (this lesson) for classrooms that have a strong interest in building, producing, and testing physical prototypes for design solutions students have been refining on paper in the previous lessons. It is assumed that not all students would be interested in that part of the design process, which is the focus of other units, such as *Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)* and *Unit 7.2: How can we help people design a flameless heater? (Homemade Heater Unit).*

Classrooms that select this optional extension should consider that such testing would not necessarily have to occur immediately following the lesson, nor would it be optimal to occur during classroom time. For students who are interested in this extension it could be offered at lunch or before or after school or could be pursued on their own at home. In all these cases, it could be pursued in parallel with other instruction at a later point in the year. This would allow you to launch a new instructional unit immediately after this lesson, such as *Unit 8.2: How can a sound make something move? (Sound Unit)*, which is the recommended scope and sequence for the program.

LEARNING PLAN FOR LESSON 15

1. Introduce the design pitch. 3 MIN

Materials: None

Introduce students to the synthesis task. Display **slide A**.

Say, *When engineers are working on a design solution they will compile all their evidence, research, and data and use it to inform decisions as they develop prototypes, drawings, and representations of their design solutions and write up their argument or recommendation of how and why a solution should be designed before moving forward with manufacturing. In the first part of class today, you will use all the materials from Lesson 14 to put together a design pitch for your design. Your design pitch should explain why your final design is effective and should be made. In your pitch include the trade-offs you have made and how you justify these trade-offs to the stakeholders. How would you explain the consequences of changing an aspect that the stakeholders were wanting in a design to something else, and how will this change benefit them and the design as compared to their original request?*

2. Construct individual design pitch. 20 MIN

Materials: science notebook, *Redesigning Your Protective Device*, *Stakeholder Feedback Form*, *Decision Matrix*, *Final Design Proposal*

Give students time to write their final proposal for their design. Project **slide B.** Tell students they should have out and be ready to use any resource material from their notebook, their *Redesigning Your Protective Device*, their *Decision Matrix*, and their *Stakeholder Feedback Form* as they complete *Final Design Proposal*. Pass out *Final Design Proposal*. Say, *You may notice you already have ideas for some of the sections on this handout on one of the handouts from Lesson 14. In that case, you may just be transferring your ideas to this document. Other sections may require more thought. Read the questions carefully and compare them with the work you have already done on your designs. Some portions of the handout may need only a little more revising or thought for your presentation proposal for potential investors.*

Assessment Opportunity

This *Final Design Proposal* handout can be used as a **formative** for pre-summative assessment readiness. As students work through the handout, check in with them and/or ask probing questions of students who might need additional assistance or guidance to gain some evidence or insight as to how ready students are for the assessment. Some examples of how to support students as they work through the different sections of this handout are included below:

Part 1: Introduce the problem and claims for a solution

- Students should already have thought through this and have it recorded on *Stakeholder Feedback Form*. If a student is stuck here and not sure what to write, ask them to look back at this handout to find the problem they identified and their solution claims that were presented to stakeholders. They can simply transfer what they wrote there to this document, or they could summarize in new wording.

Part 2: Show off your solution

- Students may become overly fixated on drawing a detailed example of their device. Remind students that they already have an example of their device drawn on *Redesigning Your Protective Device* that can be transferred over to this handout. If students have included a lot of design details on their original handout, ask them to just focus on the key features that investors would be interested in for the marketing of the device.

Part 3: Present your research

- In this section students explain what components they are keeping in their design and what components they are not keeping in their designs based on feedback they received on *Stakeholder Feedback Form* and in their notebooks when they explained constraints and prioritizations around their design. If students simply need to see what they listed as primary, secondary, and tertiary, this is available on *Decision Matrix*. They should be able to use these three pieces of data to complete this section. Guide students to look back at these as they complete this section.

Part 4: Justify your design decisions

- Suggest students complete the first two columns first using what they have completed on *Stakeholder Feedback Form* and *Decision Matrix* and what they have written in their notebook around why they made the decisions they did for their design.
- Students have already spent time at the end of Lesson 14 considering the effects of each trade-off. Refer students back to their notebooks to find their ideas over why these choices and prioritizations were made.

Say, *Though you've got some great ideas for how to improve your designs for our consumers, how could you use this way of thinking to evaluate and test designs that other engineers come up with for any proposed collision mitigation design solution? You will now use what you have figured out about contact forces and designing solutions and apply it to a new phenomenon scenario. This will be your final assessment of our unit.*

3. Part 1 Transfer Task

20 MIN

Materials: *Part 1: Cheerleading Headgear Assessment*, computer, projector, video (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

Distribute *Part 1: Cheerleading Headgear Assessment* to each student. Show **slide C**. Take a few minutes to go through the directions for the different sections of the transfer task. Then read the assessment introduction.

Show a cheerleading video to the class. Take a moment to show a video from options suggested (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**). Alternatively, any other cheerleading video that shows the aerial gymnastics of the sport can be shown.

***Attending to Equity**
For question 3b of the assessment, students are asked to support or refute their claim by citing evidence from investigations we did and using any related science ideas we developed to defend their argument. Offering

It is advised you should show at least half the video so students can see what this sport looks like, especially in a competition. This will help them think about the idea of adding helmets to the uniform for cheerleading. Answer any questions students may have about what the questions are asking of students.* Give students time to complete part 1 of the assessment on their own.

Additional Guidance

Students may have a traditional view of cheerleading which only involves cheers being conducted from the ground. Many students may have never seen a competitive cheerleading routine and may not know that gymnastics or aerial stunts are involved. Showing a competitive cheerleading video may allow students to see this competition as a sport instead of a sideline activity, and help students better answer questions regarding the injury risks that accompany the sport.

Alternate Activity

If students had previously needed additional learning experiences to show conceptual understanding on the Lesson 6 or Lesson 10 assessment and have been revising their questions as the unit has progressed, instruct students to get back out their prior assessment they have been updating during Lessons 11–14. Tell students to use their updated answers to aid them in developing their responses on both Parts 1 and 2 of the current assessment.

Assessment Opportunity

Building towards: 15.A Develop and use a series of models to represent (a) the relative strength of the forces (change and stability) being applied to three different objects and subsystems in contact in a collision, (b) in each case what interaction (cause) is producing this force (effect) on the object, and (c) the direction of these forces in three different free body diagrams and use the ideas from these models to support or refute an argument for the effect on peak forces on heads during a collision.

What to look/listen for: See *Item alignment guide* to determine which questions on *Part 1: Cheerleading Headgear Assessment* are aligned to which crosscutting concepts and related pieces of disciplinary core ideas. See *Part 1 Key: Cheerleading Headgear Assessment* for scoring guidance and anticipated responses to the related questions on *Part 1: Cheerleading Headgear Assessment*.

What to do: Refer students to examples of free body diagrams the class developed in Lessons 5, 10, and 13, as well as the examples they developed in the individual assessments in Lessons 6 and 10. Use these to help students identify the key features of a free body diagram and what force interactions are represented in each subsystem.

students a choice in modality to share their explanation provides equal access for all students. Some students may benefit from drawing a representation of the potential collision results when one cheerleader collides with another and labeling it to support why they think this. As another alternative, some students may find more success explaining this orally through recording themselves and then turning in the recording or presenting to the class or presenting to you during an appropriate time in the classroom.

4. Navigation

2 MIN

Materials: *Part 1: Cheerleading Headgear Assessment*

Conduct the end of part 1 of the transfer task. Ask students to pause where they are at on the assessment and turn part 1 in. Let them know that the rest of the part 1 assessment can be completed tomorrow if they are not finished. It can be helpful to keep separate the assessments that are from students who have completed part 1 and ones from students who have not finished and may need a few minutes to finish at the beginning of the next class.

End of day 1

5. Part 2 Transfer Task

25 MIN

Materials: *Part 2: Cheerleading Headgear Assessment*, 10 mini index tab flags of one color (e.g. green) and 10 of another color (e.g. yellow)

Distribute *Part 2: Cheerleading Headgear Assessment* to each student. Show **slide D**. Take a few minutes to go through the directions for the different sections of the transfer task.* Answer any questions students may have about what the questions are asking of students. Give students time to complete part 2 of the assessment on their own. You will also want to hand back part 1 to anyone who had not finished it in the prior class period. After 20 minutes, collect all transfer tasks. Most should have already finished by this time, but if there are still a few who are not finished, you may need to offer them time outside of class or, if it works logistically, they could finish the task and then join the class in revisiting the DQB when they finish.

Display **slide E** as students are finishing the assessment. As students finish the transfer task and have turned it in, tell them to take a few of their index tab flags and silently visit the DQB. Using the directions slide E, they should read through the questions and put one on any that they feel they can answer.

Assessment Opportunity

Building towards: 15.B Construct an explanation for why a design solution will optimize performance, including the prioritized criteria, constraints brought from stakeholders, and trade-offs made when revising the design to meet criteria.

Building towards: 15.C Design a solution to a problem to reduce the damage to an object in a collision (by reducing peak forces) by considering the properties of different materials and shapes being used to serve particular functions.

What to look/listen for: See *Item alignment guide* to determine which questions on *Part 2: Cheerleading Headgear Assessment* are aligned to which crosscutting concepts and related pieces of disciplinary core ideas. See *Part 2 Key: Cheerleading Headgear Assessment* for scoring guidance and anticipated responses to the related questions on *Part 2: Cheerleading Headgear Assessment*.

What to do: Refer to activities in Lessons 11–12 and the associated handouts for material properties and structures. Revisit the close-up and microscopic images of the protective materials and have students look for parallels in those

***Attending to Equity**
For question 5 of this part of the assessment, students are asked to write an argument for why their design solution is optimal and meets the needs of the stakeholder and to discuss what trade-offs were made and why. As part of this question, students are offered their choice of modality for expressing their explanation. They can either construct a written explanation or present their explanation orally. Offering students a choice in modality to share their explanation provides equal access for all students. Some students may benefit from drawing a representation of their design with labeling to point out how, why, and where their design solution is optimal. Some students may wish to put together this explanation using technology so they could present it to an audience while other students may wish to orally present their explanation.

properties. Analyze the data presented in Lesson 13 to spur the idea that space for air and deformation are important when selecting a cushioning material. Revisit models drawn in Lesson 13 in regards to how shape and thickness can distribute the forces over a greater area.

6. Revisit the Driving Question Board (DQB). 10 MIN

Materials: science notebook, 10 mini index tab flags of one color (e.g. green) and 10 of another color (e.g. yellow), optional: chart paper, markers

Convene in a Scientists Circle around the Driving Question Board. Look for patterns using the index tab flags. In the Scientists Circle, focus on the questions that have the most number of sticky dots.

Discuss as a class the questions the class can now answer. Have the class discuss the answers to those questions as a group. If you have space, you might make a Take-Aways board that has a record of the answers the class comes up with.*

The index tab flags are reusable. Have students remove them from board when they are done and collect them so you can reuse them with your next class.

Alternate Activity

In Lesson 6 students revisited the questions on the DQB using *Reviewing Our Driving Question Board*, and this was revisited again in Lesson 10. From Lesson 11 on, students have added new questions to the DQB. As an alternate approach to using sticky dots to revisit the DQB, you could reprint this handout and populate any new questions for students. Print out one copy per student. When they finish their transfer task, they could pick up one of these handouts and using green and yellow colored pencils or markers, they could mark the questions they can fully and partially answer.

7. Quick Write: Reflect on our experiences. 8 MIN

Materials: science notebook

Celebrate the class's accomplishments. Say, *I can't believe how far we have come since we first wondered about the phenomenon of why smart phone screens break sometimes and not other times. We should be very proud of what we have accomplished!*

Have students reflect on their experiences with the unit.* Have students return to their regular seats. Prompt students to find a new page in their science notebook and title the page "Reflection." Display **slide F**. Give students about 5 minutes to write a personal reflection on their learning based on the following prompts:

- What was most challenging in this unit?
- What was most rewarding?
- Think about how you engaged in sensemaking discussions with classmates. How would you want to engage with those experiences the next time around?

***Attending to Equity**
Revisiting the DQB is important for students to feel as though their questions are valued and recognized. Note that it is possible that not all questions will have been addressed (it's more likely that most will be at least partially answered), particularly if you have been encouraging students to keep adding to the DQB in the later lessons of the unit. This taking stock activity helps students see that they have done this hard work in service of answering most of their own questions.

*** Supporting Students in Engaging in Asking Questions and Defining Problems**
Revisiting the DQB at the end of the unit helps students see the progress they have made toward answering questions that were important to them at the onset of the unit where students were tasked with asking questions "that require sufficient and appropriate evidence to answer." Students developed ideas for investigations to pursue to answer these questions in multiple lessons throughout the unit.

- What would you do the same?
- What would you do differently?

Alternate Activity

If you have time, you could also structure this reflection as a "blizzard." For a blizzard, have students anonymously record their reflections on a piece of loose paper, crumple it up, and then throw it up in the air. Students can then pick up a ball of paper and go around one by one and read aloud what is on the paper they picked up until everybody's reflection has been shared.

As a whole group, ask each student to share part of their reflection. Taking time to reflect upon the process of this unit can allow students to think metacognitively about what works well for them as learners.

Through pursuing such investigations across the course of the unit and individual and whole-group sensemaking, they can now answer many of their own questions. This final visit to the DQB also allows students to see how their hard work toward a shared learning goal helps them figure out the phenomenon and can also explain a lot of other phenomena and help design solutions for them. This process encapsulates a recurring design pattern in all units as well as reflects the nature of larger scientific and engineering enterprises in our world.

***Attending to Equity**
This unit asks students to do meaning-making that is difficult but potentially rewarding. Taking time to reflect on the process of this unit can allow students to think about what works well for them as learners. Consider giving more time to answer these questions if needed.

OPTIONAL How can we market our designs to our potential investors?

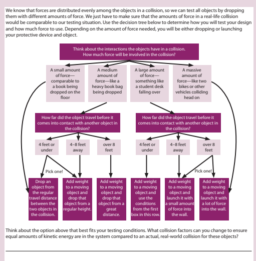
Previous Lesson

This was the last lesson of the formal unit. We evaluated other engineers' design solutions to protect cheerleaders from concussions in collisions using the science and engineering ideas we have figured out over the course of the unit. We designed our own solution and argued how it takes into consideration the criteria, constraints, and trade-offs in the proposed solution. We revisited the DQB to take stock of the questions we have answered.

This Lesson

Putting Pieces Together

4 DAYS



This is an optional extension lesson. We develop a presentation to share with potential investors about the merits of our design. We have the option to create a scale prototype and test our designs. We have additional options to add visual aids to our presentations. We present our design ideas to investors.

Next Lesson

There is no next lesson.

Building Toward NGSS

MS-PS2-1, MS-PS2-2, MS-PS3-1, MS-ETS1-2, MS-ETS1-3, MS-LS1-8

What Students Will Do

16.A Communicate and present information orally about the proposed performance of a protective device, explaining how specific structures and materials have been manipulated to reduce peak forces in a collision.

What Students Will Figure Out

- Investors care about the considerations of stakeholders.
- As a designer, information has to be presented in a clear, relevant, and engaging way that allows investors to see that all stakeholder considerations have been taken into account.

Lesson 16 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	**INTRODUCE DESIGN PITCH PRESENTATION** Discuss what investors would want to know about designs and give a presentation overview.	A-B	
2	15 min	**DISCUSS PRESENTATION OPTIONS** Go over project presentation options and select individual presentation methods.		*Presentation Format Options*, *Outlining an Investor Pitch Presentation*, *Final Design Proposal* *End of day 1*
3	135 min	**CREATE PRESENTATIONS** Create design pitch presentations to be shared with investors.		*Presentation Format Options*, *Outlining an Investor Pitch Presentation* *End of day 2*
		SCIENCE LITERACY ROUTINE Upon completion of Lesson 16, students are ready to read Student Reader Collection 6 and then respond to the writing exercise.		Student Reader Collection 6: Applying Ideas About Materials and Forces

Lesson 16 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide** **Student Work Pages**	• *Presentation Format Options* • *Outlining an Investor Pitch Presentation* • *Final Design Proposal*		

Materials preparation (15-45 minutes)

Online Resources

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

- The preparation for this lesson will vary based on time available and student project choice.
- The scale model optional activity will require time to print handout *Creating a Scale Model*.
- The creation of a prototype for testing purposes will require time to print handout *Determining Your Prototype Testing Conditions* and prepare a testing area, which will vary based upon the type of object a student is protecting and school testing conditions (see *Determining Your Prototype Testing Conditions* to review what testing conditions are recommended to students, depending on device).

- The additional visual aids project extension will require the time to print handout *Optional Project Extensions*. Depending on technology availability, preparation for the additional visual aids will vary based upon the student-selected visual aid.
- Some students who are engaging in the extension activities may have the time to create a model. The models can be done to scale or just rough sizing. To attend to equity, it is suggested that general craft supplies or materials meant to be recycled or repurposed are provided to students for their design use in the classroom.
- If students engage in *Determining Your Prototype Testing Conditions*, some students may need access to a stairwell or a slingshot launcher. If assigning this activity, ensure that the materials needed are available. Read all safety and use information if this slingshot launcher is used; this information will vary from model to model.
- If students use tools such as a hot glue gun, provide safety guidance regarding the use of that tool, including training on how to use the tool and related materials, staging, and storage.
- See *Project Options Overview* to learn more about project options, materials required for each extension, and an overview of those materials.

Lesson 16 • Where We Are Going and NOT Going

This lesson is an optional extension for use after the formal end of the unit (Lesson 15) for classrooms that have a strong interest in developing their investor presentation and/or building, producing, and testing physical prototypes for design solutions students have been refining on paper in the previous lessons. It is assumed that not all students would be interested in that part of the design process, which is the focus of other units, such as *Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)* and *Unit 7.2: How can we help people design a flameless heater? (Homemade Heater Unit)*.

Classrooms that select this optional extension should consider that such a presentation or testing would not necessarily have to occur immediately following the lesson, nor would it necessarily be optimal to occur during classroom time. For students who are interested in this extension it could be offered at lunch or before or after school or could be pursued on their own at home. In all these cases, it could be pursued in parallel with other instruction at a later point in the year. This would allow you to launch a new instructional unit immediately after this lesson, such as *Unit 8.2: How can a sound make something move? (Sound Unit)*, which is the recommended scope and sequence for the program.

The lesson plan below, however, is written as if the teacher is referring to Lesson 15 as having just occurred recently. You will want to modify the language used, therefore, to frame the work in this lesson and accompanying slides if you implement it at a different point in your instructional unit sequence.

LEARNING PLAN FOR LESSON 16

1. Introduce design pitch presentation.

5 MIN

Materials: None

Say, *Last lesson we created a final design proposal. Generally, after a design proposal is drafted, the key ideas are shared with investors in a design pitch.*

Project **slide A**. Have students turn and talk about the following question:

- If you were an investor, what would be the most important thing you would want to know about someone's proposed design solution?

After students have had time to discuss their ideas with their partner, have them share their ideas with the class. Accept all relevant responses. Students may present the following ideas:

- Investors want to know if they will make money from the design.
- Investors want to know if someone will want to buy it and if the designer considered the buyers when designing the device.
- Investors want to know if it is realistic to build.
- Investors want to know if the stakeholders were satisfied with the trade-offs.

Say, *OK, we have a good idea of what investors want, and it seems to center around stakeholder needs. That is definitely important to communicate to the investors. Let's actually draft a plan and share with our stakeholders and investors right here in class.**

Introduce the pitch presentation project. Project **slide B**. Introduce the investor design pitch project to students. Explain that students will have the opportunity to create a design pitch and present it to an audience. Tell students that there are many ways to do this, and we will consider each method as we go. If we have time, we will also be able to build a scale prototype, test it, and add other visuals to our presentation to help our investors envision this design in real life.

***Attending to Equity**

Connections to my community: This project provides a great opportunity to bridge classroom and community. During their presentation students will be presenting their learning and findings based upon ETS1.A and ETS1.B. The community will consist of stakeholders for almost every device, and this will provide a real-world opportunity for students to present a meaningful solution to stakeholders from various backgrounds. If there is time, invite stakeholders such as school leaders, officials, and community members into the classroom for these presentations. Allow the stakeholders to give to students meaningful feedback on their designs.

2. Discuss presentation options.

15 MIN

Materials: *Determine Your Presentation Format*, *Outlining an Investor Pitch Presentation*, *Final Design Proposal*

Share project options. Pass out *Presentation Format Options* to students. Explain that sometimes product designers and engineers pitch designs to investors in different locations, sometimes on the other side of the world. Because of that and increased use of technology in the workplace, there are a couple of different options for presenting their design pitch to investors.

***Attending to Equity**

Universal Design for Learning: Some students may have anxiety about presenting to others. By giving students the option to present the materials and record themselves ahead of time, part of

Go over the three different options with students:

- Presenting in person with a question and answer session after the presentation
- Prerecorded with a live question and answer session after the recording
- Presented over a live, online platform with a question and answer session after the presentation

Allow students 2–3 minutes to make their presentation choices.*

the anxiety can be lessened, and allowances for all students to have a way to *access* this activity will be provided.

Additional Guidance

If time is short to present the investor pitch presentations, consider having all students use the prerecorded option. Certain platforms like Flipgrid would allow all students to share and give each other investor feedback virtually and on a timescale that may be more appropriate to certain classrooms.

Introduce *Outlining an Investor Pitch Presentation*. After students have decided how they will present their presentation, distribute *Outlining an Investor Pitch Presentation* to students. If you have previously collected *Final Design Proposal*, make sure to pass that back at this time as well.

Explain to students that when designers or engineers present to investors, investors want to know that the stakeholders' needs have been addressed. Because of that, this information is paramount in their presentations. *Outlining an Investor Pitch Presentation* will help students plan for their presentation to investors by having them think thoughtfully about the information on *Final Design Proposal* and determine how they will present the information.

Begin creating the presentation. Provide students with time to complete *Outlining an Investor Pitch Presentation* using their information from *Final Design Proposal*. Once students are finished planning their presentation, allow students to begin creating their presentation. Students have several options to choose from for creating this presentation. As students are working, make sure that all students are utilizing the information from *Outlining an Investor Pitch Presentation* in their presentation.

End of day 1

3. Create presentations.

135 MIN

Materials: *Presentation Format Options*, *Outlining an Investor Pitch Presentation*

Allow students time to complete their presentations in the method they have identified on *Presentation Format Options*.

Additional Guidance

Note that this presentation preparation period is designated for 3 days. This timeline can be altered or extended to meet the needs of students, or it can run parallel to a new unit, as suggested by the scope and sequence pacing. This entire lesson can also be moved to a different time in the school year as an opportunity to revisit the science ideas and align with school-designated, in-school community nights.

Students can also engage in optional activities with this presentation based upon time allotted, student interest, needed enrichment, and ability level. See *Project Options Overview* for details on each option.

Present the pitch. After students have completed the creation of their presentation, give time for students to present their pitches to stakeholders and/or investors. Potential applicable assessable standards for math, English language arts, and technology standards (depending on project and extension choice) can be found on *Potential Accompanying Standards*. Before a presentation begins, distribute *Investor Design Feedback Form* to all stakeholders and/or investors engaging with the presentation.

Assessment Opportunity

Building towards: 16.A Communicate and present information orally about the proposed performance of a protective device, explaining how specific structures and materials have been manipulated to reduce peak forces in a collision.

What to look/listen for: Listen for students to demonstrate understanding of ideas of performance expectations that were not fully met at the end of Lesson 15.

- Students should list trade-offs and the reasoning behind those trade-offs to optimize their design solution.
- Listen for the rationale for decisions that led to the optimization of the design.
- Listen for students to include a rationale for their material choice that involves the properties of their material that help reduce peak forces during a collision, such as the ability of materials to deform, space for air, and distribution of contact forces over a greater surface area.
- See *Potential Accompanying Standards* for details on additional standards to assess, if wanted.

What to do: This is the second and additional time to assess the understanding of material properties, shapes, and structures that reduce peak forces in a collision. If students do not include this, ask students during the question and answer section of the presentation why they have chosen those specific materials and what they do to reduce peak force. This presentation provides an additional opportunity to check in on these ideas, and this additional assessment opportunity may not be needed for all students.

Give feedback. As the presentation is conducted, remind the stakeholders and/or investors to use *Investor Design Feedback Form* to give feedback on the design. At the end of the presentation, provide 2-3 minutes for stakeholders to ask questions and give feedback to each student.

Alternate Activity

At the end of the presentations, consider also doing a gallery walk of prototypes and other developed materials to celebrate student work. *Investor Design Feedback Form* can also be used for this activity.

SCIENCE LITERACY: READING COLLECTION 6

Applying Ideas About Materials and Forces

1 **Egg Drop Competition**
2 **Debate Transcript**
3 **Controlling Collision Factors**

Literacy Objectives

- ✓ Summarize key points related to applications of materials and force.
- ✓ Distinguish cause(s) and effect(s) related to acceleration, mass, and force.
- ✓ Contrast pros and cons of a proposal to ban plastic bottles.

Literacy Exercises

- Read varied text selections related to the topics explored in Lessons 14–16.
- Evaluate the reading selections according to provided prompts and criteria.
- Compare and contrast information gained from reading text with information gained from class investigation.
- Prepare a well-reasoned paragraph in response to the reading.

Instructional Resources

Student Reader

Collection 6

Science Literacy Student Reader, Collection 6
"Applying Ideas About Materials and Forces"

Exercise Page

EP 6

Science Literacy Exercise Page
EP 6

Prerequisite Investigations

Assign the Science Literacy reading and writing exercise *after* class completion of this lesson group:

- Lesson 14: How can we use our science ideas and other societal wants and needs to refine our designs?
- Lesson 15: How can we use what we figured out to evaluate another engineer's design?
- Lesson 16: OPTIONAL How can we market our designs to our potential investors?

Standards and Dimensions

NGSS

Disciplinary Core Ideas PS2.A: Forces and Motion For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law). (MS-PS2-1); **ETS1.B: Engineering Design** Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors.

Science and Engineering Practice: Obtaining, Evaluating, and Communicating Information

Crosscutting Concept: Cause and Effect

CCSS

English Language Arts

RST.6-8.6: Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text.

RST.6-8.10: By the end of grade 8, read and comprehend science/technical texts in the grades 6-8 text complexity band independently and proficiently.

WHST.6-8.4: Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Core Vocabulary

Core Vocabulary: Core Vocabulary terms are those that students should learn to use accurately in discussion and in written responses. During facilitation of learning, expose students repeatedly to these terms. However, these terms are not intended for isolated drill or memorization. No Core Vocabulary is introduced in this reading collection.

Language of Instruction: The Language of Instruction consists of additional terms, not considered a part of Core Vocabulary, that you should use when talking about any concepts in this exercise. Students will benefit from your modeling the use of these words without the expectation that students will use or explain the words themselves.

acceleration	**context**
efficacy	**mandate**
standards	**terminal velocity**

A Glossary at the end of the Science Literacy Student Reader lists definitions for Core Vocabulary and selected Language of Instruction.

1. Plan ahead.

Determine your pacing to introduce the reading selections, check in with students on their progress, and discuss the reading content and writing exercise. If you are performing Science Literacy as a structured, weekly routine, you might implement a schedule like this:

- Monday: Designate a ten-minute period at the beginning of the week to introduce students to the assignment.
- Wednesday: Plan to touch base briefly with students in the middle of the week to answer questions about the reading, to clarify expectations about the writing exercise, and to help students stay on track.
- Friday: Set aside time at the end of the week to facilitate a discussion about the reading and the writing exercise.

Exercise Page

EP 6

2. Preview the assignment and set expectations.

- Let students know they will read independently and then complete a short writing assignment. The reading selection relates to topics they are presently exploring in their Contact Forces unit science investigations.
- The reading and writing will be completed outside of class (unless you have available class time to allocate).
- Preview the reading. Share a short summary of what students can expect.
    - *First, you will read a science investigation report by a pair of fictional eighth graders who designed a container to prevent raw eggs from breaking in a 15-foot drop.*
    - *Recall that you read in an earlier collection how plastics are useful in designing ways to reduce collisions. Here, you'll read a simulated transcript from a debate about banning the importation of plastic bottles to a small island nation.*
    - *Lastly, you'll read an article that summarizes ways to control collisions so that they cause less damage.*
- Distribute Exercise Page 6. Preview the writing exercise. Share a summary of what students will be expected to deliver. Emphasize that Science Literacy exercises are brief. The focus is on thoughtful quality of a small product, not on the assignment being big and complex.
    - *For this assignment you will be expected to generate a well-reasoned paragraph to settle the argument in the unit preface about factors that affect how much it hurts to hit the water when you jump in.*
- Remind students of helpful strategies they can employ during independent reading. Offer the following advice:
    - *The reading should take approximately 30 minutes to complete.* (Encourage students to break reading into smaller sections over multiple short sittings if their attention wanders.)
    - *A good reading strategy is to scan through the collection first to see the titles, section headers, graphics, and images to see what the selections are going to be about before fully reading.*
    - *Next, "cold read" the selections without yet thinking about the writing assignment that will follow.*
    - *Then, carefully read the Exercise Page to understand the expectations for the writing part of the assignment.*
    - *Revisit the reading selections to complete the writing exercise.*
    - *Jot down any questions for the midweek progress check in class.* (Be sure students know, though, that they are not limited to that time to ask you for clarification or answers to questions.)

3. Touch base to provide clarification and address questions. (WEDNESDAY)

Touch base midweek with students to make sure they are on track while working independently. You may choose to administer a midweek minute-quiz to give students a concrete reason not to postpone completing the reading until the last minute. Ask questions such as these, and have students jot answers on a half sheet of paper:

Suggested prompts	Sample student responses
What did the students Will and Stephania do to increase their device's air resistance?	*They cut four 24-inch streamers and attached them to the box that held the egg.*
According to the debater opposed to the ban, what societal needs are met with plastic bottles?	*Certain essential products are almost exclusively packaged in plastic bottles, such as shampoo, dish soap, disinfectants, and medicines.*
Why do huge oceangoing ships often travel one or two miles after "brakes" are applied to stop them?	*because they have a huge mass and the water does not provide much friction to slow them down*

Ask a few brief discussion questions related to the reading that will help students tie the text content to students' classroom investigations.

Suggested prompts	Sample student responses
How did Will and Stephania make sure that their design would deform to reduce the force of collisions?	*They made a nest out of loose insulation materials inside the box, added the egg, and then put more insulation on top of it.*
Niue's problem is that there is too much plastic bottle litter on the island, much of it soda bottles. One solution is to ban importing plastic bottles to the island. Who are the stakeholders related to this problem?	*children of the island, their parents, tourists, the government employees, and anyone who depends on the economy of the island*
In our investigation, we called acceleration a "change in motion." How does the table of falling objects show acceleration, or a change in motion?	*It shows that speed increases with time as an object falls toward Earth.*

- Refer students to Exercise Page 6. Provide more specific guidance about expectations for students' deliverables due at the end of the week.
  - *The writing expectation for this assignment is to compose a well-constructed paragraph that interprets and answers the questions raised in the Preface to this unit about jumping into a lake.*
  - *That means you'll want to reread the Preface and find the claims made by the different characters.*
  - *Then, you'll use what you have learned in this unit, paying special attention to the last selection in Collection 6, to explain what factors really affect how hard you hit the water when you jump in.*
  - *Use your concluding sentence to present your final word on the lake scenario and who, if anyone, was most correct.*
  - *The important criteria for your work are that you state the relationship between force, mass, and acceleration accurately and use it to explain what happens in various collisions.*
- Answer any questions students may have relative to the reading content or the exercise expectations.

Exercise Page

EP 6

4. Facilitate discussion.

(Friday)

Facilitate class discussion about the reading collection and writing exercise. The first selection is an engineering task report by two fictitious eighth graders who designed, built, and tested a device to protect an egg from breaking in a 15-foot fall.

Pages 54–63 **Suggested prompts**	**Sample student responses**
What is the general purpose of the first selection, "Egg Drop Competition"?	*It reports on an engineering assignment two students carried out in their science class, describing the procedure students followed and discussing their results.*
What was the problem they needed to solve?	*how to design a device to protect a raw egg from breaking when dropped 15 feet onto a sidewalk*
What were the criteria and constraints of the task?	*Criteria: the egg had to be uncracked after a 15-foot fall; the egg had to be extra-large size and cold; only biodegradables could be used to make the device.* *Constraints: no plastic other than 6 inches of tape; no fixed wings, propellers, or parachutes*
What is the general purpose of the second selection, "Debate Transcript"?	*It is a transcript of a debate among legislators in a small Pacific island nation about banning plastic bottles from being imported into their country.*

Student Reader

Collection 6

SUPPORT—If you are using the recommended word envelope convention, check the envelope to see if it contains any words, phrases, or sentences that students need help understanding. Read key sentences aloud, and provide concise explanation.

Online Resources

Pages 54–63 **Suggested prompts**	**Sample student responses**
What is the point of view of each speaker?	*Each speaker is telling their perspective in the first person.*
How does the second selection help you build knowledge on top of what you learned in the Collection 4 third selection about plastics?	*The article in Collection 4 reveals some properties of plastics that make them desirable but also, generally, why they are not recycled. The debate in this collection details what factors make it difficult to recycle plastic bottles in a small Pacific island nation.*
How could combining some of the ideas for dealing with plastics result in a better solution than outright banning them or having no restrictions at all?	*The island could ban only plastic soda bottles and allow plastic bottles for shampoo, soap, disinfectants, and medicine. Then they could have a smaller tax to pay for the export of remaining plastic bottles to a facility that recycles them.*
What is the general purpose of the third article, "Controlling Collision Factors"?	*It explains how differences in acceleration or mass affect motion and collisions on land, in water, and when objects fall through the air.*
How was this article useful in writing your paragraph about the Preface scenario?	*It had a couple of paragraphs, a photo, and a caption that interpreted the scenario and explained that mass affects the force of collision and that speed increases with time as the object falls directly downward, also increasing the force of collision. It also explained that the shape the person takes as they hit the water can concentrate the force on parts of the body that can handle the collision with less pain.*
Based on your design work in Lessons 14–16, is there any kind of equipment people jumping into water could use to prevent injuries?	*Maybe they can wear a soft shirt or wetsuit to cushion the impact of the collision with the water.*

SUPPORT—Guide students to understand that plastics differ in their chemical composition and properties. For this reason, not all plastics are easily recyclable. Have students compare the recycling symbols printed on various plastics and learn which classes of plastics are recyclable and which are not.

EXTEND—Allow interested students to view Olympic platform diving videos and analyze how the divers collide with the water. Students should notice how the divers position their arms depending on the type of dive and lock their hands together before collision with the water to reduce the amount of splashing and avoid injury.

5. Check for understanding.

Evaluate and Provide Feedback

For Exercise 6, students should write a well-constructed paragraph to settle the argument among the friends introduced in the Preface scenario. Students' explanations should use cause-and-effect language to discuss how mass, acceleration, differences in elevation, and the shape of the object colliding with the water affect the force with which it collides with a body of water.

Use the rubric provided on the Exercise Page to supply feedback to each student.

Teacher Resources

Table of Contents

ASSESSMENT SYSTEM OVERVIEW

Each unit includes an assessment system that offers many opportunities for different types of assessments throughout the lessons, including pre-assessment, formative assessment, summative assessment, and student self-assessment. The table below outlines where key assessments can be found in the unit. Key formative assessments are identified here, but many more opportunities are embedded in each lesson, and guidance for those also appears in the following table.

Each unit includes an assessment system that offers many opportunities for different types of assessments throughout the lessons, including pre-assessment, formative assessment, summative assessment, and student self assessment. Formative assessments are embedded and called out directly in the lesson plans. Please look for the “Assessment Icon” in the teacher support boxes to identify places for assessments. In addition, the table below outlines where each type of assessment can be found in the unit.

Overall Unit Assessment

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 1	Initial Model: Objects During Collisions	**Pre-Assessment** Lesson 1 is an opportunity to uncover students’ initial ideas and questions about how damage sometimes happens to objects in collisions. Analyzing student work will allow you to see if students have skills from prior grade bands (what a force is, balanced and unbalanced forces, energy is transferred in collisions, energy can be transferred through forces, and so forth) and if they have some current grade-band understandings (mass and speed as factors related to kinetic energy; net force ideas; and so forth). Use students’ initial models of collisions and the Consensus Discussion as a pre-assessment opportunity. In the Consensus Discussion, it is best if you select students who will share a wide variety of ideas. Disagreement among students about what causes damage to objects in a collision will motivate students to find answers throughout the unit. Disagreement will also help students develop a Driving Question Board with questions they will answer throughout the unit.
Lesson 4	Independent, Dependent, and Controlled Variables	**Formative** At the start of Lesson 4, students express their initial ideas about important variables in an investigation. The handout *Independent, Dependent, and Controlled Variables* can be used as a reference for students throughout the unit and throughout 8th grade as they continue to design and carry out investigations.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 5	Slide K and related science notebook entry	**Formative** This is a good opportunity to determine if students can plan investigations in small groups without a lot of scaffolding. Slide K cues students to start planning their investigation with their group. You can assess much of this plan before groups go to carry out the investigation and collect the data from it. Look for • identification of a single independent variable • identification of the dependent variables • identification of important variables to keep constant • a data table with results from at least two conditions tested • peak forces measurements and/or equalities or inequalities noted for both push-pull spring scales for each condition tested • results from repeated trials for each condition (optional) • source(s) of error in the system (optional)
Lesson 6	Soccer Assessment Soccer Assessment Key	**Formative** This is a putting-the-pieces-together lesson. It includes an assessment that provides students an opportunity to apply their understanding of peak forces, damage, and kinetic energy on different parts of a system in a collision. Students also draw free-body diagrams of the parts of a system during a collision. It's critical that students first understand that the forces during a collision are always equal and opposite and that the peak forces experienced by each object are the same before they attempt to make a free-body diagram describing that relationship. However, once students become adept at using the free-body diagram to describe forces and energy transfer as objects interact, they will better be able to use free-body diagrams to predict the changes in motion to objects and changes in kinetic energy in a collision.
Lesson 10	Lesson 10 Assessment Lesson 10 Assessment Key	**Summative and Formative** This is a putting-the-pieces-together lesson. It includes a summative midpoint assessment that can provide formative information for moving forward in the unit. The goal of the assessment is to determine if students can apply their evidence from lab activities and key science ideas to explain how objects sometimes break when they hit each other. This lesson is also an excellent opportunity to revisit the Driving Question Board to identify questions that can be answered so far. The lesson includes guidance for supporting students in selecting their own questions they feel they can now answer and sharing those answers with the class. This lesson assessment also provides an additional opportunity to re-assess students over ideas presented in Lesson Set 1.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 11	Protection Device Design Thinking Drafting Our Protection Device Design	**Pre-assessment** This lesson provides an opportunity to find out what students may already understand about the relationship between material properties and their abilities to reduce peak forces in a collision. Students will draw a diagram of their own protective device designs for an object of their choice and will try to describe these protective materials from a microscopic and macroscopic level, giving an idea of student understanding of scale, system models, and structure and function of the materials. Students will develop their understanding of how material properties reduce peak forces on the objects they are protecting in Lessons 12–14.
Lesson 14	Lesson 14 Device Redesign	**Summative** This is a putting-the-pieces-together lesson. It includes a summative assessment that gives students the opportunity to explore various types of padding and explain how padding helps ensure that objects in collisions change motion using small forces over long distances (rather than large forces over short distances). Then students apply their understanding from the entire unit to their own design idea. These material properties are used to refine designs, and trade-offs of different material choices are examined. Students have to apply the ideas of structure and function while considering stakeholder feedback and trade-offs to optimize their designs (ETS1).
Lesson 15	Part 1: Cheerleading Headgear Assessment Part 2: Cheerleading Headgear Assessment Part 1 Key: Cheerleading Headgear Assessment Part 2 Key: Cheerleading Headgear Assessment Item alignment guide	This lesson provides an end-of-unit assessment to assess student understanding of peak forces, material structure, net force, and equal and opposite forces relationships. Students apply this knowledge to evaluate cheerleading helmets for safety, support or refute claims about the protective qualities of the device, explain the structural properties of protective materials and how they can contribute to a reduction of peak forces on the object they are protecting, and design a new device while considering the needs of stakeholders. This end-of-unit assessment provides evidence of student understanding in the concepts above and an additional opportunity to assess key ideas from Lesson Sets 1 and 2. See the alignment guide for further details about the alignment of questions to the science and engineering practices, crosscutting concepts, and disciplinary core ideas for the unit.
After each lesson	Lesson Performance Expectation Assessment Guidance	**Formative Assessment** Use this document to see which parts of lessons or student activity sheets can be used as embedded formative assessments.

When	Assessment and Scoring Guidance	Purpose of Assessment
Occurs in most lessons	Progress Tracker	**Formative and Student Self-Assessment** The Progress Tracker is a thinking tool that was designed to help students keep track of important discoveries that the class makes while investigating phenomena and figure out how to prioritize and use those discoveries to develop a model to explain phenomena. It is important that what the students write in the Progress Tracker reflects their own thinking at that particular moment in time. In this way, the Progress Tracker can be used to formatively assess individual student progress or for students to assess their own understanding throughout the unit. Because the Progress Tracker is meant to be a thinking tool for students, we strongly suggest it is not collected for a summative "grade" other than for completion.
Anytime after a discussion	Student Self-Assessment Discussion Rubric	**Student Self-Assessment** The student self-assessment discussion rubric can be used anytime after a discussion to help students reflect on their participation in the class that day. Choose to use this at least once a week or once every other week. Initially, you might give students ideas for what they can try next time to improve, such as sentence starters for discussions. As students gain practice and proficiency with discussions, ask for their ideas about how the classroom and small-group discussions can be more productive.
After students complete substantial, meaningful work	Peer Feedback Facilitation: A Guide	**Peer Feedback** There will be times in your classroom when facilitating students to give each other feedback will be very valuable for their three-dimensional learning and for learning to give and receive feedback from others. We suggest that peer review happens at least two times per unt. This document is designed to give you options for how to support this in your classroom. It also includes student-facing materials to support giving and receiving feedback along with self-assessment rubrics where students can reflect on their experience with the process. Peer feedback is most useful when there are complex and diverse ideas visible in student work, and not all work is the same. Student models or explanations are good times to use a peer feedback protocol. They do not need to be final pieces of student work, rather, peer feedback will be more valuable to students if they have time to revise after receiving the peer feedback. It should be a formative, not summative, type of assessment. It is also necessary for students to have experience with past investigations, observations, and activities where they can use these experiences as evidence for their feedback.

For more information about the approach to assessment and general program rubrics, visit the Teacher Handbook.

Lesson-by-Lesson Assessment Opportunities

Every lesson includes one or more lesson-level performance expectations (LLPEs). The structure of every LLPE is designed to be a three-dimensional learning, combining elements of science and engineering practices, disciplinary core ideas and cross cutting concepts. The font used in the LLPE indicates the source/alignment of each piece of the text used in the statement as it relates to the NGSS dimensions: alignment to Science and Engineering Practice(s), alignment to Cross-Cutting Concept(s), and alignment to the Disciplinary Core Ideas.

The table below summarizes opportunities in each lesson for assessing every lesson-level performance expectation (LLPE). Examples of these opportunities include student handouts, home learning assignments, progress trackers, or student discussions. Most LLPEs are recommended as potential formative assessments. Assessing every LLPE listed can be logistically difficult. Strategically picking which LLPEs to assess and how to provide timely and informative feedback to students on their progress toward meeting these is left to the teacher's discretion.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 1	**1.A** Develop a model to describe interactions between two objects as they collide and show the changes that occur in the structure of both objects when one object is damaged as a result and also when neither object is damaged as a result. **1.B** Ask questions that arise from observations of collisions between two objects in order to seek additional information about factors (causes) that might affect the outcome of such collisions.	**1.A Developing and Using Models; Stability and Change; Systems and System Models** **When to check for understanding:** Collect students' initial models on *Initial Model: Objects During Collisions* and explanations on *Object Interactions During a Collision* at the end of day 1 to pre-assess their fluency in developing a model. **What to look for/listen for:** Prompts in this task ask students to engage in two elements of the modeling practice related to representing descriptive aspects of the phenomenon as well as unobservable mechanisms. These will provide an opportunity for students to use related DCIs from prior grades; grade 4 (energy transfer in collisions) and grade 2 (objects push each other when they collide). There are phrases in the prompts that ask students to consider related elements of CCCs, particularly systems and system models and stability and change. You may also see some students developing particle-level representations for changes happening in the matter in the system, based on their extensive work in developing such models in prior units. See the related *Assessment* callout box for additional guidance. **1.B Asking Questions and Defining Problems; Cause and Effect** **When to check for understanding:** Since students will put their initials on the backs of these sticky notes, you will have a few opportunities to take stock of the kinds of questions students ask in this initial lesson after they are posted on the DQB as well as when they first write them. When students share these questions for the DQB, they will likely have time to share only one. Collect the remaining questions that don't get posted after the development of the DQB is complete. This record of questions they form today will help you formatively assess their fluency in the practice of asking questions at the start of this year. Collect and look through student notebooks to see their individual ideas for future investigations to pursue as well. **What to look for/listen for:** See the related *Assessment* callout box for additional guidance.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 2	**2.A** Collect data on changes in the motion and shape of colliding objects that serve as the basis for evidence that energy transfer occurs during the collision and that there are forces between colliding objects. **2.B** Construct an argument supported by empirical evidence and scientific reasoning to support a model showing that changes in motion of colliding objects (connected to subsystems) results from energy transfer between them (cause) and changes in the shape of those objects results from force(s) between them (cause).	**2.A Planning and Carrying Out Investigations; Stability and Change** **When to check for understanding:** Students carry out two investigations to explore what happens in collisions on day 1 of the lesson. In the first, the *Dropping and Breaking Lab*, they explore what happens to objects during a collision by dropping rigid objects on other objects. Students encounter challenges in understanding what's happening at the moment of contact in collisions and help identify a plan for the *Exploring Horizontal Collisions Lab* to improve their ability to make observations. **What to look/listen for:** Listen for students to suggest ways to control the collisions they observe. For example, students will likely suggest the use of slow-motion video or zoomed-in images of the moment of collision. They are likely to suggest that they want to see how the materials themselves are changing during the time the objects are in contact with each other. They may also suggest ways to control the motion and speed of objects in collisions, such as a way to target or line up the objects to ensure that they will collide after one or both are put into motion. **2.B Engaging in Argument from Evidence; Stability and Change; Cause and Effect; System and System Models** **When to check for understanding** 1. Students develop cause-and-effect statements to account for mechanisms responsible for the changes in motion and shape during collisions in day 2 of the lesson. 2. Students also update their Progress Trackers at the end of day 2 with what they figure out related to their lesson question. This provides a second opportunity to formatively assess student understanding. **What to look/listen for** 1. Students making arguments that leverage prior knowledge about changes in kinetic energy, energy transfer, and/or forces in the initial cause-and-effect statements they make 2. Students making claims that refer to how energy transfer can help account for changes in motion and for how forces can account for changes in shape (students may also mention that forces can account for changes in motion as well)
Lesson 3	**3.A** Construct and revise a written argument using evidence from various sources of data (slow-motion videos, photos, and firsthand investigations) to support or refute the claim that all objects do bend or change shape when pushed in a collision.	**3.A Engaging in argument from evidence; stability and change** **When to check for understanding:** Check for student progress in their responses they write for their initial claim on in their notebooks. **What to look/listen for:** Students should identify that the evidence supports the claim that all objects bend or change shape when pushed in a collision.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 4	**4.A** Plan an investigation, identifying controls to keep constant, and carry out the investigation to produce data to serve as the basis for evidence to develop a mathematical model for the relationship (pattern) between the amount of force applied to an object and the amount it deforms. **4.B** Analyze and interpret graphical data (patterns) from tests of compression force vs. amount and type of deformation (temporary vs. permanent) to provide evidence that supports an argument that all objects behave elastically up to a specific limit beyond which permanent damage occurs (stability and change).	**4.A Planning and Carrying out Investigations; Patterns, Cause & Effect, Stability & Change** **When to check for understanding:** Completion of *Independent, Dependent, and Controlled Variables* will provide a useful reference text for future investigations that students will plan in small groups in later lessons and future units in 8th grade. **What to look/listen for:** Look for students to do the following in the planning of the investigation: • identify the independent variable as the amount of force applied to an object, • identify the dependent variable as the amount of deformation in the object, and • identify controls including where the force is applied and how much of the object overlaps the two supports (bricks) in each test. **4.B Analyzing and Interpreting Data; Patterns, Cause & Effect** **When to check for understanding** Students construct graphical displays of data from compression force vs. deformation tests to help identify a linear relationship that describes the elastic behavior of all objects in graphs they make at the end of day 1 on *Deformation Results.* **What to look/listen for** • the *x*-axis labeled as the force applied to the object (in N) • the *y*-axis labeled as the amount of deformation in the object (in cm) • stretching out the intervals to maximize the use of the graph paper while still capturing the highest *x* value and highest *y* value • equal intervals identified on each axis • a straight line of best fit through the data that are represented with points drawn as open circles (anywhere the beam returned to its original shape after the weight was removed)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 5	**5.A** Plan and carry out an investigation and identify patterns in the data collected from the investigation to provide evidence that when peak contact forces on each object during the collision are equal in strength, the strength of those forces increases when the mass or the speed of the object that was moving before the collision increases. **5.B** Develop and use subsystem models (free body diagrams) to represent how the peak contact forces on two different objects compare in a collision and how these are related to corresponding changes in the kinetic energy of a moving object before it collides due to a change in its mass or the speed.	**5.A Plan and Carry out Investigations; Patterns, Systems and System Models** **When to check for understanding: Slide K** cues students to start planning their investigation with their group. You can assess much of this plan before groups go to carry out the investigation and collect the data from it. **What to look/listen for** 1. **Identification of a single independent variable:** mass or speed 2. **Identification of the following dependent variables:** the peak force measured on the push-pull spring scale on cart subsystem A and the peak force measured on the push-pull spring scale on cart subsystem B 3. **Identification of important variables to keep constant:** If students identified mass as the independent variable then they should identify speed as an important variable to try to keep constant. If students identified speed as the independent variable then they should identify mass as an important variable to try to keep constant. 4. **A data table** with results from at least two conditions tested (e.g., no additional mass vs. added mass or slower speed vs. faster) 5. **Peak forces measurements** and/or equalities or inequalities noted for both push-pull spring scales for each condition tested 6. **Results from repeated trials for each condition** (optional) 7. **Source(s) of error in the system** (optional) **5.B Develop and Use Models; Systems and System Models** **When to check for understanding:** Collect student exit tickets at the end of day 2 of this lesson. **What to look/listen for:** Transferring the representations of the ideas developed in the class consensus model to a new context to explain a different phenomenon. The following ideas should be show up in students' responses: • A: Students identify one or both objects. • B: The forces would be equal in strength. • C: The kinetic energy would be less. • D: The forces would be weaker but still equal in strength.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 6	**6.A** Apply science ideas and use evidence to construct an explanation for how the amounts of peak force and energy transfer (cause) in soccer collisions result in instability in the brain (concussions, effect) due to sudden changes at the cellular level.	**6.A Constructing Explanations and Designing Solutions; Cause and Effect; Stability and Change** **When it happens:** Students use science ideas from Lessons 1-5 in *Soccer Assessment* to determine how peak forces and energy transfer affect different soccer collision scenarios. **What to look/listen for** • Peak forces on the head and the ball are shown as the same during a header, both drawn in the diagram in question 1 and the selected answer in question 2a. • Contact forces are applied to both objects and are always equal regardless of speed or mass in question 2b. • Identification of case c in questions 3a and 3b as having the least amount of total kinetic energy in they system before the collision. • Collisions with objects that are moving with a greater mass or speed in comparison with collisions that have lesser mass and speed will experience more peak force, as seen in the two potential answers for question 5. • See *Soccer Assessment Key* for a more detailed analysis of what to look for in each question.
Lesson 7	**7.A** Construct, analyze, and interpret graphical displays of data collected from a computer simulation to identify patterns in the data, including a linear relationship between the mass of a moving object and its kinetic energy and a nonlinear relationship between the speed of a moving object and its kinetic energy. **7.B** Construct an explanation based on quantitative relationships (scale) for whether decreasing the mass of a moving object or decreasing its speed would have a bigger effect on the peak forces produced in a collision between it and a stationary object and use these ideas to further explain why this would cause damage in some collisions but not others (effect).	**7.A Analyze and Interpret Data; Patterns** **When it happens:** On day 2 of the lesson when students construct two graphs of their data from the computer simulation on copies of *Graphing Kinetic Energy Relationships* and when they discuss the patterns they notice in these with a partner, per slide K, and then share these patterns with the whole class **What to look for:** See the assessment callout box for guidance on what to look for in students' graphs and student discussions. **7.B Constructing explanations and designing solutions; scale, cause and effect** **When it happens:** At the end of day 2 of the lesson when students individually complete questions 3-5 on *Looking back: Explaining and predicting kinetic energy changes in the system* **What to look for:** See the assessment callout box for guidance on what to look for in student responses.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 8	**8.A** Develop and use a model to identify other parts of the system the cart and box are making contact with or colliding into that could be producing contact forces on these subsystems, causing energy to be transferred to or from them as the box and cart travel down the track.	**8.A Develop and use a model, systems and system models, energy and matter.** **When it happens:** In the student responses you collect on *Modeling other force interactions in the launcher, cart, box, and track system* at the end of the lesson **What to look for:** See *Key for modeling force interactions in the launcher, cart, box, and track system* for guidance on what to look for in student responses.
Lesson 9	**9.A** Apply scientific ideas and evidence to construct an explanation for the causes of motion and kinetic energy changes that happen before and after collisions and how these affect the outcome of a collision. **9.B** Respectfully provide and receive critiques about claims to identify relevant evidence to support an explanation for how energy transfers through the cart-launcher system before and right after a collision. **9.C** Develop and revise a model to identify other parts of the system the cart and box are making contact with or colliding into that are producing contact forces on these subsystems, causing energy to be transferred to or from them as the box and cart travel down the track.	**9.A Planning and Carrying Out Investigations; Cause and Effect** **When to check for understanding:** In day 1 of this lesson, students carry out investigations and examine data at four stations to build understanding of forces due to friction and air resistance and how these affect motion and kinetic energy (KE) of subsystems in the collision system model. **What to look for:** Students should use the patterns they notice to develop cause-effect relationships between observable changes at the macroscopic scale and the particle nature of interactions at the microscopic scale. Students should attribute slowing down or losing energy to particle interactions due to air resistance and friction between surfaces that slide past each other. **9.B Engaging in Argument from Evidence; Energy and Matter** **When to check for understanding:** After students collect evidence and analyze data on day 1 of this lesson, they write claims about the cause-effect relationships between changes in motion and in kinetic energy and particle nature of interactions due to friction and air resistance. They will present and defend their claims on day 2 and engage in discussion to deepen their thinking. **What to look for:** Listen for students to share similarities and differences in the evidence and reasoning they cite to support their claims. Students should be describing the relationship between the particle nature of air and the surfaces of objects sliding past each other. **9.C Develop and use a model, systems and system models, energy and matter.** **When it happens:** In the revised student responses on *Modeling other force interactions in the launcher, cart, box, and track system* you will collect at the start of the next lesson after redistributing the previously collected responses back to students at the end of this lesson **What to look for:** See *Key for modeling force interactions in the launcher, cart, box, and track system* for guidance on what to look for in student responses you will collect at the start of Lesson 10. Compare the responses with those students provided at the end of Lesson 8.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 10	**10.A** Apply scientific ideas to explain why some collision-related phenomena resulted in damage while others did not and to explain how the contributing factors (energy, matter, peak forces) could change to result in different collision outcomes. **10.B** Apply scientific ideas to explain multiple baseball phenomena, including the effects of air density and wind on ball speed (changes to the stability of the system and its effect on kinetic energy changes due to air resistance), bat mass vs. bat speed (interpreting patterns in graphical and tabular data to determine the linear and nonlinear effects on increases of kinetic energy within the system), and bat type (the effect deformation has on peak forces in the system and kinetic energy) on how the game is played.	**10.A Constructing Explanations and Designing Solutions; Cause and Effect; System and System Models** **When it happens:** Students use *Explaining a Collision* to explain why a collision type resulted in damage or no damage during a collision and what factors (mass, speed, KE, friction, air resistance) could be altered to produce a different collision outcome. **What to look/listen for:** Look for students to use the ideas off of the Big Ideas poster. In box 1, look for these ideas: • representing the kinetic energy of the moving object as greater than that of the nonmoving object • forces due to air resistance and friction acting on the moving object before the collision • force arrows that are representative of the relative amounts of force acting in the moving object and in the proper direction and whose arrow tip is touching the surface the force is acting on In box 2 look for these ideas: • objects bending or deforming (momentarily or permanently) • each object experiencing the same amount of peak force, but in opposite directions • energy being transferred in the system between the colliding objects at the moment of contact • Optional: If the objects are made of different materials, they could show different amounts of deformation for the same amount of force. Though students know this should be the case based on ideas they figured out in Lesson 4, because they won't know the relative elasticity of each object in the system, they may not feel it's valid to represent these relative differences in their models without having these specific data to inform which object would deform more or less than the other. In box 3 look for these ideas: • change in speed being represented as a larger factor than change in mass in reducing or increasing kinetic energy of the moving object(s) • greater or less air resistance and friction causing the increase or reduction of kinetic energy of the moving object(s) before the collision • changes listed above having an effect on the amount of deformation of each object at the moment of collision • changes in the amount of deformation of each object corresponding to whether or not it exceeds the elastic limit of the object to account for whether or not it is damaged

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
		10.B Constructing Explanations and Designing Solutions; Cause and Effect; Systems and System Models; Stability and Change **When it happens:** Students complete *Baseball Assessment 1* or the alternate version *Baseball Assessment 2* on day 2 of the lesson. **What to look for** • Questions 1-2: Students should show a decrease in ball speed attributed to the loss of energy due to air resistance. Students should justify this idea using free-body diagrams showing the relative strengths of air resistance due to wind speed. • Question 3: Students should use ideas for investigations that utilize experiences from previous labs in class. • Questions 4-6: Students will plot points based upon data, then predict a data point based on the line of best fit. • Question 7: Students should explain that an increase in bat mass would decrease swing speed due to the amount of energy needed to move a more-massive object. • Questions 8-9: Students should reflect an understanding that speed increases at a greater rate when kinetic energy is doubled. A decrease in air resistance would increase the visible effects of this relationship. • Question 10: Students should argue the warning on the bat supports the coach's claim that it produces higher peak forces in a collision than other bats, but nothing on the warning provides information to support the claim that it deforms less in a collision. • Questions 11-12: These answers are subjective to viewpoint; see *Key 1: Baseball Assessment* and *Key 2: Baseball Assessment*. • See *Key 1: Baseball Assessment* and *Key 2: Baseball Assessment* for a more-detailed assessment guidance by question.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 11	**11.A** Define a problem that can be solved with the development of a protective device to reduce damage (peak force) during a collision by identifying and considering multiple criteria and constraints along with specific materials, shapes, and designs of devices that reflect our science ideas of how certain material properties function in a collision. **11.B** Design a solution to a problem to reduce the damage to an object in a collision (by reducing peak forces) by considering the properties of different, individual materials and shapes being used to serve particular functions.	**11.A Asking Questions and Defining Problems; Structure and Function** **When it happens:** Students engage in defining a problem that could be solved with the design of a protective device for an object and identifying the overall purpose of a protective device in *Protection Device Design Thinking*. Students identify criteria and constraints and consider what materials and properties are important to the protective device. **What to look for/listen for:** On *Protection Device Design Thinking* students define the purpose at the top of the page. Look for students to identify that the purpose of the device is for protection. Look for relevant criteria and constraints as students engage with the handout and for justification of the type of material and the shape of the materials they propose to use in their designs. **11.B Constructing Explanations and Designing Solutions; Structure and Function** **When it happens:** Students engage in designing a protective device for an object of their choosing when they complete *Drafting Our Protection Device Design*. **What to look for/listen for:** Treat this as a pre-assessment of students' understanding of new ideas that they will develop in the last lesson set of the unit. The first idea is related to the microscopic structure of cushioning materials. Many effective cushioning materials provide pockets or gaps of space or air between the layers of materials for the cushioner to "give". Look for this in the second column of the design drawing. The second idea is related to how cushioners reduce peak forces in a collision. Look for these concepts: • The amount of peak force is reduced because the cushioner applies a weaker force over a larger distance in a collision, which has as much effect on reducing the kinetic energy of an object as a stronger force over a shorter distance. • These forces are transferred to both objects that the cushioner is in contact with (including the object it is protecting). • The shape of a cushioner can be designed to distribute that force over a greater surface area, thereby reducing the amount of peak force occurring at a single location on the object being protected.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 12	**12.A** Analyze data to determine which materials reduce peak force in a collision and analyze the similarities (visual patterns across materials) in the properties of those materials (macroscopic deformability). **12.B** Develop a model to explain how the changes in the structures of cushioning materials contribute to their function (a reduction in peak forces) at a microscopic level during a collision.	**12.A Analyzing and Interpreting Data; Structure and Function, Patterns** **When to check for understanding:** At the beginning of day 2, students individually reflect on data from the investigation to analyze the structure of multiple materials and look for patterns in structure. Students identify what structural patterns they see in the top performers and try to explain how these patterns in structure could better reduce peak force than other materials that did not perform as well. **What to look for/listen for** As students are individually reflecting on data, they should write about the patterns they see across multiple structures that were top performers. Students should identify that the better performers have space and/or air gaps in them and the ability to deform more than other materials that did not perform as well. **12.B Developing and Using a Model; Structure and Function** **When it happens:** *How can materials reduce peak force on the objects they protect?* provides an opportunity for formative assessment. Circulate as students are working on their explanations and collect the handout at the end of class. **What to look for/listen for** • Bubble wrap and cotton balls have a large amount of empty space or air in them and relatively small amounts of solid material across the space they take up. • Bubble wrap and cotton balls deform easily when a small force is applied. • Connecting structure to function, identifying a connection to reduction in peak force: e.g., less force between the cushioner and the object it is in contact with is due to increased space, ability to deform, less-solid material, more-flexible material, and so forth. • Possible student idea: Students may bring up particle-level connections, e.g., these materials are ones that would also exhibit less energy transfer through conduction from prior units which may be related to less peak force.

<table>
<tr><th>Lesson</th><th>Lesson-Level Performance Expectation(s)</th><th>Assessment Guidance</th></tr>
<tr><td>Lesson 13</td><td> 13.A Construct an explanation for how (and why) the structure of a cushioning material affects the peak forces produced (function) in a collision, relating the amount of space available for deformation, the total contact time during a collision, and the peak forces produced from the addition of such structures. 13.B Develop and use subsystem models (free body diagrams) to represent how the peak contact forces on different objects in a collision compare when they have different cushioning structures between them. 13.C Critically read a scientific text adapted for classroom use to determine how concussions can result in breaks in the axons of neurons (structure) and why this can lead to memory loss (function), how a snug fit (structure) for a helmet would affect its performance (function), and how other changes in the structure of cushioning material (in a helmet) would affect its performance (function). </td><td> 13.A Constructing Explanations and Designing Solutions, Developing and using models; patterns, structure and function When it happens: When students enter an individual Progress Tracker entry at the end of the first day of the lesson What to look for: Good cushioning (force reduction) materials have space available in them for deformation.
More space available for deformation is related to an increased contact time during the collision.
Increased contact time in the collision is related to decreased peak forces produced in the collision.
Optional: Students may argue that thicker cushioning materials with spaces or air gaps in them available for deforming should therefore reduce peak forces more in a collision. 13.B Developing and using models; structure and function, stability and change When it happens: Slide H cues students to complete Free body diagrams for collisions with and without cushioning structures on their own after working on other parts of it with a partner. What to look for: Look for the system diagram and free body diagrams shown in the related assessment support box. 13.C. Obtaining, evaluating, and communicating information; structure and function When it happens: Reading: Anatomy of a Bike Helmet is distributed as a home learning assignment to be completed before the start of Lesson 14. Collect this completed assignment at the start of Lesson 14. What to look for: Use of structure and function relationships in the responses to the questions on Reading: Anatomy of a Bike Helmet. See the related assessment guidance support box for more question-specific guidance. </td></tr>
</table>

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 14	**14.A** Optimize the performance of a design by prioritizing the particular functions and properties of materials based upon stakeholder feedback to assess the relative effectiveness of the materials. **14. B** Engage in a quantitative analysis using prioritized scores and consider the trade-offs of prioritizing particular uses and functions of materials to assess their relative effectiveness for the optimization of the design.	**14.A Constructing explanations and designing solutions; Structure and function** **When to check for understanding:** On day 2, students use *Additional Material Considerations Matrix* to assign rankings to their chosen considerations as primary, secondary, or tertiary considerations. **What to look/listen for:** Look for students to appropriately assign primary, secondary, and tertiary criteria based on stakeholder feedback from *Decision Matrix*. **14.B Constructing explanations and designing solutions; Structure and function** **When to check for understanding:** On day 2, students will complete a three-column table in their notebooks considering the consequences of their design trade-offs and prioritization of considerations. **What to look/listen for:** Look for students to list the design decisions they have made according to their redesign table and decision matrix. Students should explain the potential effects (which can be positive or negative) that each design decision will specifically have on stakeholder concerns or considerations. In column 3 students will consider what effect the decision will have on the overall design of the device and explain how those decisions impact the performance of the design (which can be positive or negative).

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 15	**15.A** Develop and use a series of models to represent (a) the relative strength of the forces (change and stability) being applied to three different objects and subsystems in contact in a collision, (b) in each case what interaction (cause) is producing this force (effect) on the object, and (c) the direction of these forces in three different free body diagrams and use the ideas from these models to support or refute an argument for the effect on peak forces on heads during a collision. **15.B** Construct an explanation for why a design solution will optimize performance, including the prioritized criteria, constraints brought from stakeholders, and trade-offs made when revising the design to meet criteria. **15.C** Design a solution to a problem to reduce the damage to an object in a collision (by reducing peak forces) by considering the properties of different materials and shapes being used to serve particular functions.	**15.A Developing and Using a model; stability and change, cause and effect** **When it happens:** At the the end of day 1, students start part 1 of the assessment on *Part 1: Cheerleading Headgear Assessment*, where some of the questions on it (see *Item alignment guide*) are aligned to this practice and these related crosscutting concepts. **What to look/listen for:** See *Part 1 Key: Cheerleading Headgear Assessment* for scoring guidance and anticipated responses. **15.B and 15.C Constructing explanations and designing solutions; structure and function, cause and effect; stability and change** **When it happens:** During day 2, students complete part 2 of the assessment on *Part 2: Cheerleading Headgear Assessment*, where some of the questions on it (see *Item alignment guide*) are aligned to this practice and these related crosscutting concepts. **What to look/listen for:** See *Part 2 Key: Cheerleading Headgear Assessment* for scoring guidance and anticipated responses.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 16	**16.A** Communicate and present information orally about the proposed performance of a protective device, explaining how specific structures and materials have been manipulated to reduce peak forces in a collision.	**16.A Obtain, evaluate, and communicate information; Structure and function** **When it happens:** This investor pitch presentation provides an additional opportunity after *Part 1: Cheerleading Headgear Assessment* or *Part 2: Cheerleading Headgear Assessment* to assess skills regarding the understanding of structure and function of material properties to reduce peak forces in a collision. An informal version of this assessment can be conducted while students are completing *Outlining an Investor Pitch Presentation*, and a formal assessment can occur during the investor pitch presentation (live or prerecorded). **What to look/listen for** • Listen for students to demonstrate understanding of the unit key ideas that were not fully met at the end of Lesson 15. See *Item alignment guide* for specific key ideas. • Students should list trade-offs and the reasoning behind those trade-offs to optimize their design solution. • Listen for the rationale for decisions that led to the optimization of the design. • Listen for students to include a rationale for their material choice that involves the properties of their material that help reduce peak forces during a collision, such as the ability of materials to deform, space for air, and distribution of contact forces over a greater surface area. • See *Potential Accompanying Standards* for details on additional standards to assess, if wanted.

Making Sugar Glass

Below are instructions on how to make sugar glass in a rectangular 2″ × 3″ size that is approximately 1/16″ thick. The sugar glass is an analog for cell phone screens.

Refer to the Materials Preparation section of the *Teacher Guide* for specific directions about how to use the sugar glass after it is made. To help you plan, the following table outlines how many pieces of sugar glass you'll need for each lesson per class (based on six groups of students in a class). You will need to multiply the total per class by how many classes you teach to arrive at the grand total number of sugar glass pieces you'll need to prepare altogether. You may want to prepare 20% extra for accidental breakage.

Number of sugar glass pieces needed					
Lesson	**Per student**	**Per pair**	**Per group**	**Per class for whole-group demonstration**	**Total for one class (based on 30 students in 6 groups)***
2			1		
5			4		

Adjust if you have more or fewer than 30 students per class. Then, multiply this number by the number of classes you teach to plan how many pieces of sugar glass you need to prepare altogether.

To make the sugar glass, you will need the following:

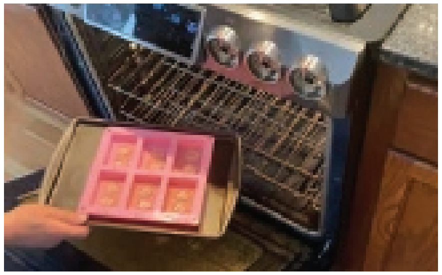
- 1.1-lb bag of Arcor Crystal Mints (note: You may also use Matlow's Hard Mint Candy or Jolly Ranchers, however, melting times may vary slightly.)
- 16-cavity silicone soap mold measuring approximately 3″ × 2″ × 1″ per cavity
- 1 cookie sheet
- 1 cooling rack
- 1 can of nonstick cooking spray
- 1 resealable, plastic storage bag, gallon size
- an electric or gas oven
- 1 roll of wax paper
- paper towels
- 2 oven mitts or hot pads
- 1 splash goggles

The directions for preparing this recipe are shown here, and you may also watch a video demonstration. (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**) The total time to prepare the sugar glass is around 25 minutes. The active time is 10 minutes.

Preheat your oven to 325 °F. Place the silicone mold on a cookie sheet Put a quick, quarter-sized squirt of nonstick cooking spray in the middle of each cavity in the mold. Use your fingers to spread the spray around the bottoms and sides. Make sure that none of the spray is pooled in the corners. Remove excess spray by wiping with a paper towel.

Place 2 unwrapped candies in each cavity. Make sure the candies are spaced evenly in the cavities and not touching the sides.

Place the cookie sheet and mold on the middle rack of your oven.



Caution: Melted sugar can cause severe burns. If it gets on the skin, it will stick to the skin and continue to burn until you take appropriate countermeasures. Follow these safety precautions when taking the melted sugar out of the oven in the next steps: Wear splash goggles. Make sure you have feet, legs, and arms covered (e.g., closed-toed shoes, long pants, and long-sleeve shirt).

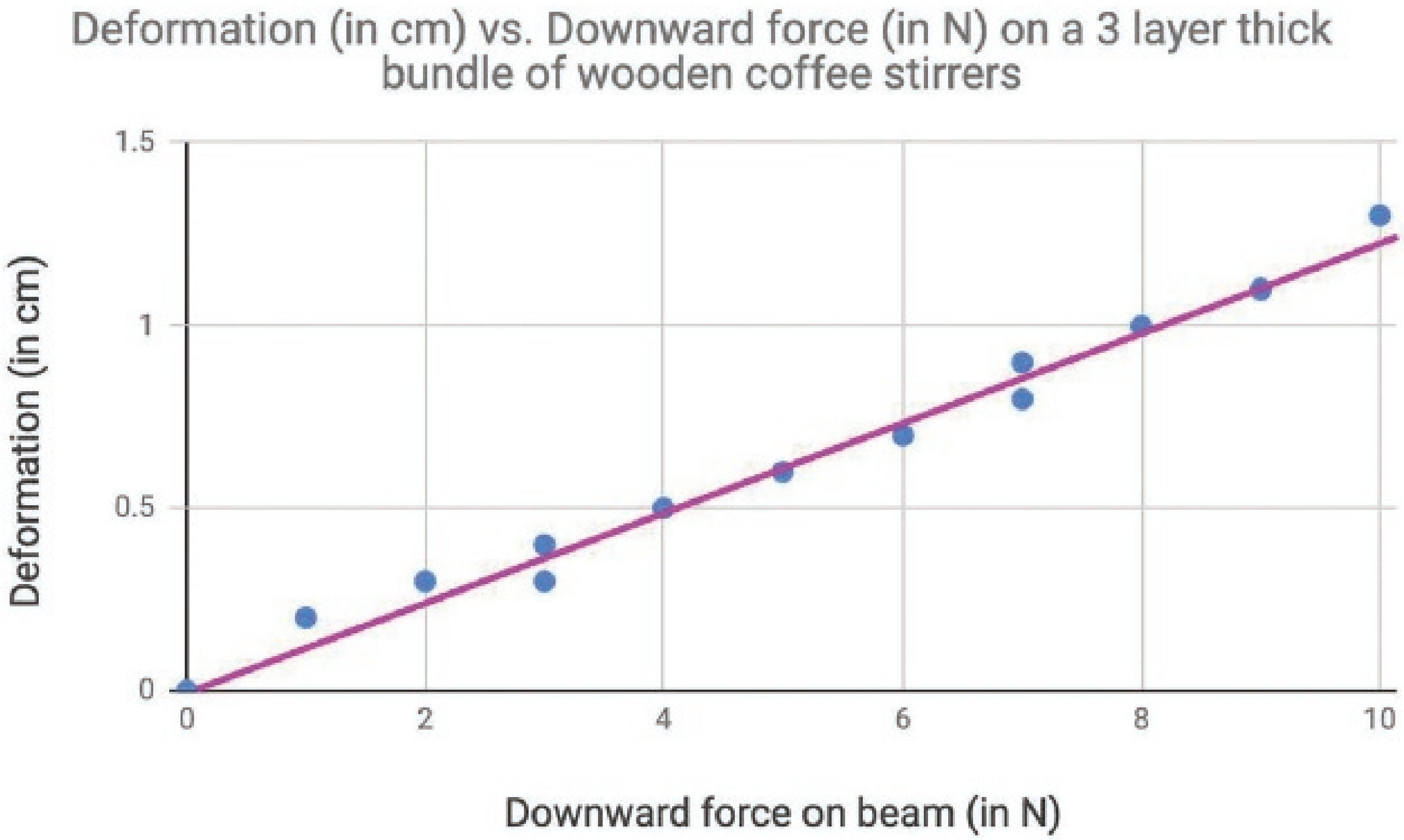
Use oven mitts to remove the cookie sheet and mold containing the melted sugar. Have cold water handy in case any melted sugar gets on your skin. If hot sugar burns skin, place skin in cold water (not ice). If done within the first minute or so, cold water immersion for up to 30 minutes can reduce total area and severity of the burn.

After approximately 15 minutes, the candy will melt, bubble, and fill the mold. (Note: this time will vary based on your oven and the candies used.) Remove the cookie sheet and mold from the oven and set it on the cooling rack. The melted candy should fill the entire mold after about 10 seconds. Some bubbles are normal. If it does not, place them back in the oven for another 2 minutes.

In approximately 10 minutes, the sugar glass will have cooled and hardened. Gently remove the sugar glass by pushing on the back of the molds.

Stack the sugar glass between pieces of wax paper and place in a sealable plastic bag until ready to use.

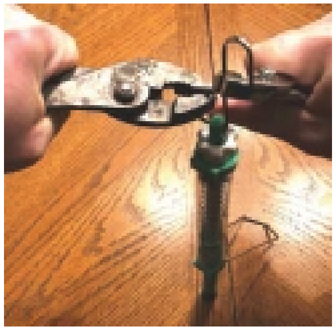
Example Line of Best Fit



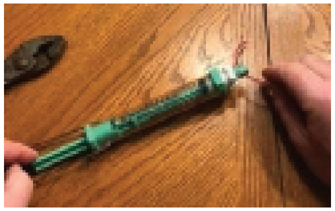
Spring Scale and Cart Modifications and Setup

Examine your 5-N push-pull spring scales. If these have a wire S hook on the end, bend the hook apart using two pliers until there is a large enough gap to slide the wire S hook out of the hole on each push-pull spring scale.

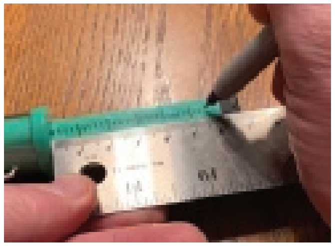
Save these S hooks as they will be needed for day 1 of this lesson when students will need to hook ends of two push-pull spring scales together for the pulling investigation they conduct.



Cut a 2-inch-long piece of wire and thread it through the hole. Then twist the two ends of the wire together.

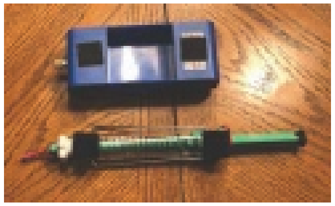


Zero each of your push-pull spring scales and keep checking this as you start to make markings on the plunger beam. Use a very fine tip permanent marker and a ruler to mark graduations every 2 mm on the flat side of the push-pull spring scale plunger.

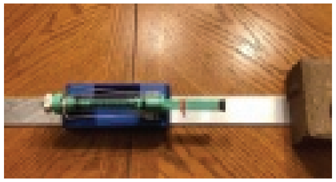


Do this for all your push-pull spring scales until you reach the end of the plunger beam. If you make a mistake you can wipe off the marking using rubbing alcohol and a paper towel. You will need to do this quickly before the ink has long to dry and let the surface dry before trying to re-mark them.

Cut two squares, ½″ × ½″ each, of hook and loop fasteners. Attach the fuzzy (loop) side on push-pull spring scales at the two locations shown. Attach the rough (hook) side to the cart at the same distance apart as the pieces you put on the spring scales.



Attach the push-pull spring scales to the carts with the markings facing up. Twist a twist tie tightly over the plunger beam. It should be tight against the plunger but should slide back and forth on it easily.



Build two of these carts for each station. Secure aluminum track to each testing station surface with painters tape. Leave 6 large washers and a small amount of modeling clay at each station.

Name: ______________________ Date: ______________________

Soccer Assessment

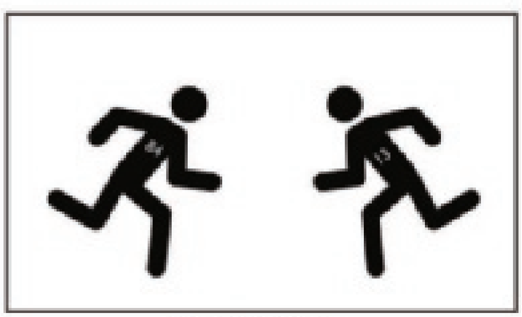
Soccer is becoming more and more popular in the United States. And while other soccer-related injuries are happening less frequently, youth soccer players in the United States are experiencing more concussions. A concussion is a type of traumatic brain injury caused by the head experiencing an impact and moving quickly back and forth, causing the brain to bounce around in the skull.

A concussion can result from a force of 400–1,000 N on the head. There has been debate in different sports about how to best prevent concussions. In soccer, one idea is to ban headers (when a ball makes contact with a head) in youth and professional soccer.

1. How would the forces from a header with such a light soccer ball cause a concussion? Draw two free body diagrams showing how the amount of peak force on the head would compare to the amount of peak force on a soccer ball in a header that causes a collision.

There are three types of collisions that tend to happen frequently in soccer: (a) headers, (b) collisions between players' heads, and (c) a player's head hitting the ground.

System A



System B

System C

2a. How would the amount of force on the head compare to the amount of force on the object it collides with in each system A, B, and C?

a. In every collision, the peak force on the head would be the same as the peak force on the other object in the collision.

b. In some, but not all collisions, the peak force on the head would be the same as the peak force on the other object in the collision.

c. In every collision, the peak force on the head would be different than the peak force on the other object in the collision.

2b. Explain in words or pictures your choice in 2a.

Sports scientists concluded that concussions result from headers, a running player colliding with another running player, and a running player hitting the ground. So far in this unit, we have looked at collisions and how much kinetic energy the objects in the system have before they collide and how this is related to the peak forces they can produce in any collision. Let's consider the three main types of systems that can lead to concussions and make predictions about them using forces and energy as it relates to player #84.

3a. Considering both objects that are about to collide in each interaction, which system would you predict to have the least amount of total kinetic energy in the system right before the objects collide? In each instance below, player #84 is running at a speed of 7 miles per hour. Circle one.

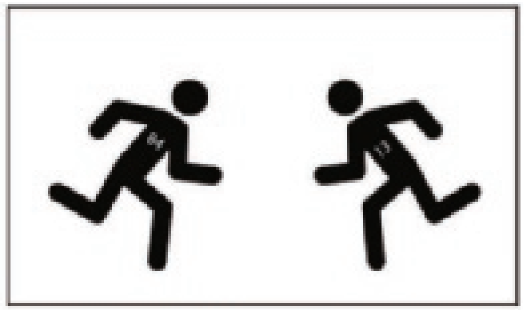
a. Player #84 running and heading the soccer ball that was kicked by another player

b. Player #84 running and colliding with another running player running towards them

c. Player #84 running and hitting the ground

3b. Explain in words and pictures using the images below why the system you chose in 3a would have the least amount of total kinetic energy before the collision by comparing it with the two other systems.

System A



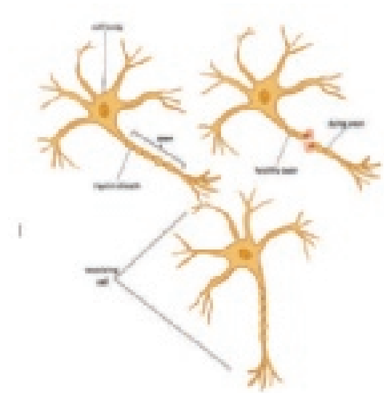
System B

System C

4. Based on your answer in 3b, which system should have the least amount of peak forces during the collision? Why?

5. The brain is an organ made of interconnected cells called neurons. Neurons send signals to communicate information from one neuron cell to another. The long part of the neuron is called an axon, and those axons have a breaking point. Recent research provides evidence that permanent damage to axons in the brain occurs from just a single damaging head collision (concussion).

   Write an argument: During a head collision, which system (A, B, or C) would be most likely to cause damage to some of the axons in the brain? Use ideas related to kinetic energy, peak forces, and breaking point for these structures in the brain, axons, in your argument.



6. Do you think the mass of a moving object or its speed is a bigger factor contributing to its kinetic energy and the resulting damage that it can do in a collision? Why? Use any experiences you've had as evidence in your argument as well as any science ideas you think are relevant.

7. Suggest one or more ways we could use the materials from previous investigations to determine whether doubling the mass of a moving object or doubling its speed has a bigger effect on the amount of damage that occurs in a collision.

Soccer Assessment Key

Scoring Guidance. The elements described below would be considered an exemplary response at this point in the unit. These are shown as purple text or in purple diagrams below the related question. In some cases different elements of the response are identified with a separate + symbol. These +'s are not meant to be all inclusive; they are suggestions for what you may see your students include.

If several of the ideas marked with a + are missing from a student's response, this may indicate the student has not mastered the science ideas or that the student may be struggling to bring those ideas together in a written explanation or model. Additional probing of their thinking can provide insight about whether the student is struggling with a science practice or science idea, or both. If all or almost all of the ideas marked with a + are present in a student's response, this may indicate the student has mastered the science ideas and is able to use them in a written explanation or explanatory model.

Soccer is becoming more and more popular in the United States and while other injuries are happening less frequently, youth soccer players in the U.S. are experiencing more concussions. A concussion is a type of traumatic brain injury caused by the head moving quickly back and forth and the brain bouncing around in the skull.

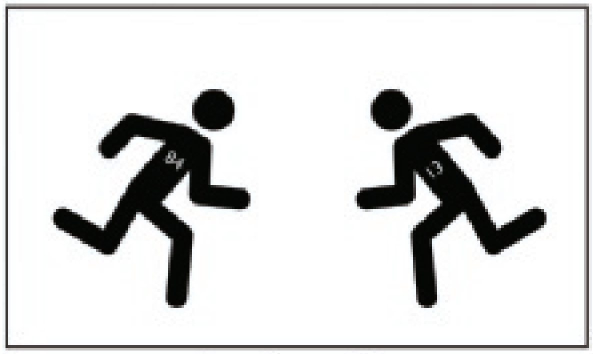
A concussion can result from a force of 400–1000 N on the head. There has been debate in different sports about how to best prevent concussions. In soccer, one idea is to ban headers (when a ball makes contact with a head) in youth and professional soccer.

1. How would the forces from a header from such a light soccer ball cause a concussion? Draw two free-body diagrams showing how the amount of peak force on the head would compare to the amount of peak force on a soccer ball in a header that causes a collision.

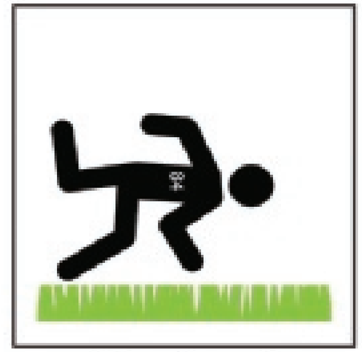
An example of what a student free body diagram could look like is shown here:

There are three types of collisions that tend to happen frequently in soccer: a) headers, b) collisions between players' heads and c) when players' heads hit the ground.

System A



System B



System C

2a. How would the amount of force on the head compare to the amount of force on the object it collides with, in each system A, B, and C?

a. In **every** collision, the peak force on the head **would be the same** as the peak force on the other object in the collision.

b. In **some, but not all** collisions, the peak force on the head **would be the same** as the peak force on the other object in the collision.

c. In **every** collision, the peak force on the head **would be different** than the peak force on the other object in the collision.

Correct response is a.

2b. Explain in words or pictures your choice in 2a.

Student responses should include these ideas:

+ You can't have force on only one object when it makes contact with another object (forces come in pairs).

+ These contact forces are always equal, even if one object has more mass or more speed before they make contact in a collision.

Sports scientists concluded that concussions result from headers, a running player colliding with another running player and a running player hitting the ground. So far in this unit, we have looked at collisions and how much kinetic energy the objects in the system have before they collide and how this is related to the peak forces they can produce in any collision. Let's consider the three main types of systems that can lead to concussions and make predictions about them using forces and energy as it relates to Player #84.

3a. Considering both objects that are about to collide in each interaction, which **system** would you predict to have the **least amount** of total kinetic energy in the system right before the objects collide? In each instance below, Player #84 is running at a speed of 7 miles per hour. Circle one.

A. Player #84 running and heading the soccer ball that was kicked by another player

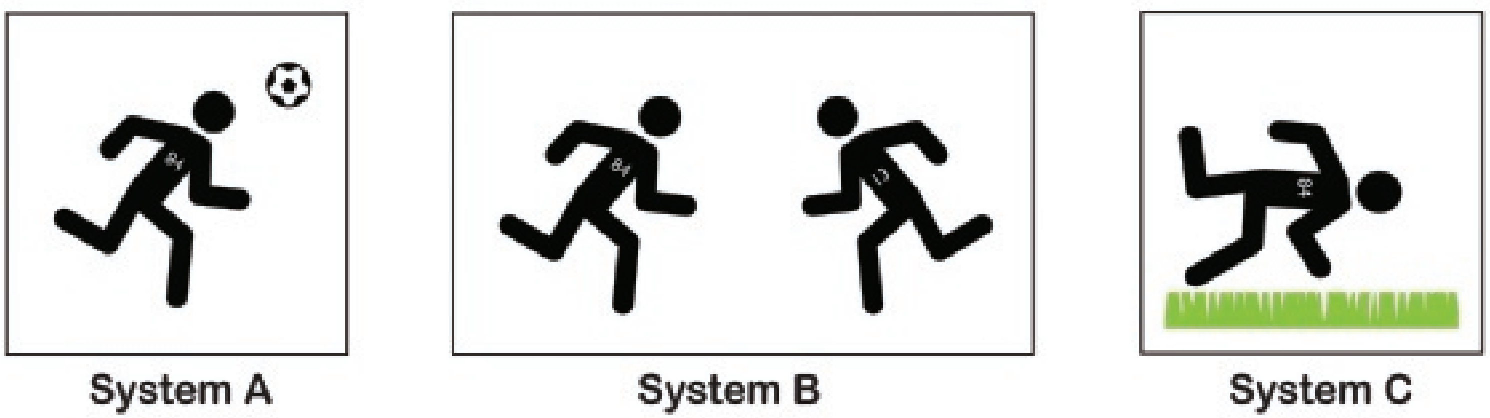
B. Player #84 running and colliding with another running player running towards them

C. Player #84 running and hitting the ground

Expected response:

C

3b. Explain in words and pictures using the images below why this system would have the least kinetic energy before the collision by comparing it with the two other systems.



Student responses should include these ideas:

+ There are two objects in each system (A, B, and C) that will collide; the total KE is based on both.

+ In each system (A, B, and C) player #84 would have the same amount of KE because in each case it's the same player with the same mass and speed.

+ The ground is not moving in system C, so it has no KE.

+ There is a second object moving in A and B (a ball or another person), meaning each of these also have KE.

+ So therefore, the total KE in system C should be lower than the other two systems.

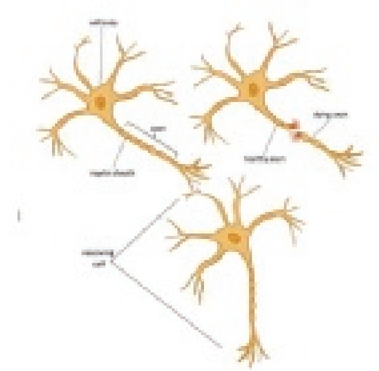
4. Based on your answer above, which system should have the least amount of peak forces during the collision? Why?

Student responses should include these ideas:

+ Total peak force is related to the amount of total KE in the system.

+ So the system with the least KE (system C) should result in the least amount of peak force during the collision.

5. The brain is an organ made of interconnected cells called neurons. Neurons send signals to communicate information from one cell to another. The long part of the neuron is called an axon, and they have a breaking point. Recent research provides evidence that permanent damage to axons in the brain occurs from just a single damaging head collision (concussion).



Write an argument: During a head collision, which system (A, B, or C) would be most likely to cause damage to some of the axons in the brain? Use ideas related to kinetic energy, peak forces, and breaking point for the structures in the brain, axons, in your argument.

Student argument should be either of the following:

+ The collision in system A is more likely to cause damage to the brain because a soccer ball can move really fast, and speed is related to KE . . . OR

+ The collision in system B is more likely to cause damage to the brain because another person running is big and has a lot of mass, and mass is related to KE.

Student chain of reasoning should include the following:

+ Mass is more important than speed for total KE or vice versa (we don't have strong evidence for resolving which is more important yet, so either response is justifiable for this prompt).

+ The peak force is related to the amount of total KE in the system before the collision.

+ So the system with more KE should result in a higher peak force during the collision.

+ The axons will only break if the peak force exceeds their breaking point.

+ This is why system A (or system B) is more likely to cause damage to some cells in the brain in a collision.

6. Do you think the mass of a moving object or its speed is a bigger factor contributing to its kinetic energy and the resulting damage that it can do in a collision? Why? Use any experiences you've had as evidence in your argument as well as any science ideas you think are relevant.

Look for justification from real-life experiences.

Capitalize on the differences of ideas and circumstances—some students will say mass, others will say speed (a speeding bullet vs. an elephant running).

Students may or may not add ideas about KE or energy transfer.

Utilize this difference to navigate into Lesson 7 at the end of Lesson 6. Guidance is provided in the Teacher Guide for this.

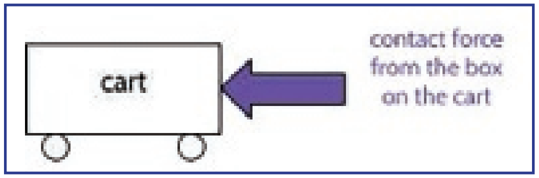
7. Suggest one or more ways we could use the materials from previous investigations to determine whether doubling the mass of a moving object or doubling its speed has a bigger effect on the amount of damage it does in a collision.

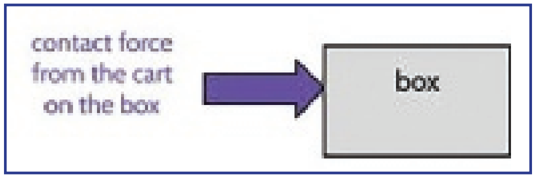
Look for any ideas that students suggest. These ideas prime students' thinking for the work they will do in the next lesson where they will collect data from an investigation around this question.

Key for Modeling Force Interactions in the Launcher, Cart, Box, and Track System

Treat this as an informal assessment of prior knowledge related to how forces from friction and air resistance act on moving objects. Do not correct preconceptions at this point. Make a copy of student responses on *Modeling other force interactions in the launcher, cart, box, and track system* so you can return the original to students to use when they revise their models for home learning in the next lesson. This will also provide you a reference to compare student thinking now (before Lesson 9) to what they are thinking later by the end of Lesson 9. Purple responses below show the target ideas you are looking for students to be using by the end of Lesson 8.

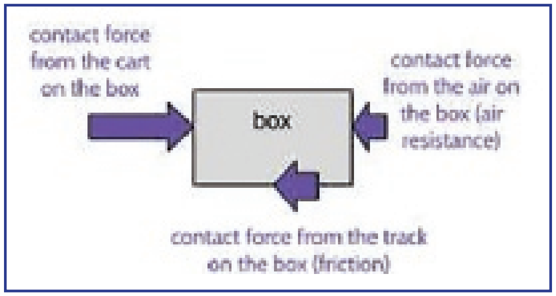
Q1) Draw and label two free body diagrams showing the contact forces between the box and the cart as they are moving together at time 4.





Q2) Besides the cart, what other objects or subsystems is the box either making contact with or colliding with at time 4?
The track and the air

Q3) Redraw your freebody diagram for the box to the right. Show all of these additional forces on it as well as the contact force from the cart at time 4. Don't worry about representing the relative strength of these forces. Focus on showing which direction the forces would be pushing on the box and which surface they would be pushing on it.



Q4) Do you think these kinds of forces are also acting on the cart as it coasts down the track at time 2? Why?

+ Air resistance would also be acting on the cart as it coasts down the track because it is an object moving through the air, hitting air particles as it goes. The cart is kind of box shaped, so the front face of it would have similar forces from air resistance on it in the same direction as those shown for the box.

+ Friction would be acting on the cart wheels, but they aren't sliding over the track like the box and there is less surface area in contact with the track, so there would be less friction on the cart from contact with the track than on the box from contact with the track.

Q5) Where does this tell you some of the energy in the system might be going as the box and cart move down the track??

+ Some of the energy might be transferred to the air.

+ Some of the energy might be transferred to the track.

Related Phenomena List

Collision Type A A moving object was damaged OR wasn't damaged when it collided with a motionless object.	
Caused damage	Did not cause damage

Collision Type B A motionless object was damaged OR wasn't damaged when a moving object collided with it.	
Caused damage	Did not cause damage

Collision Type C A moving object was damaged OR wasn't damaged when it collided with another moving object.	
Caused damage	Did not cause damage

Name: ______________________ Date: ______________________

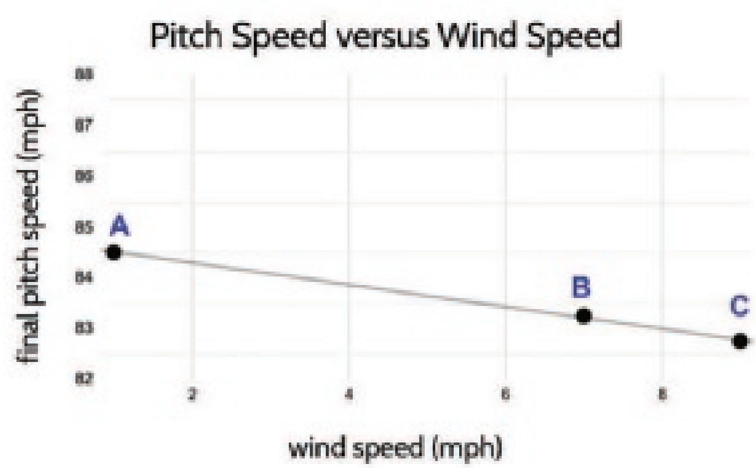
Baseball Assessment 1

At each level of organized baseball, there are rules in place about what type of bat and ball can be used. These rules help ensure the game play remains competitive, fair, and fun. The type of bat and ball are the two major factors that game organizers can control. But there are a lot of other factors that people claim also have a big impact on game play that cannot be controlled, such as weather conditions, location of the stadium, and the strength of the players.

Answer the prompts below to figure out how these factors could impact the game of baseball.

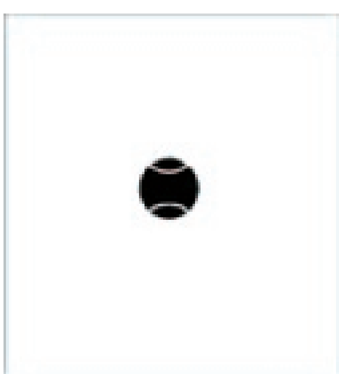
Weather Conditions and Pitch Speed

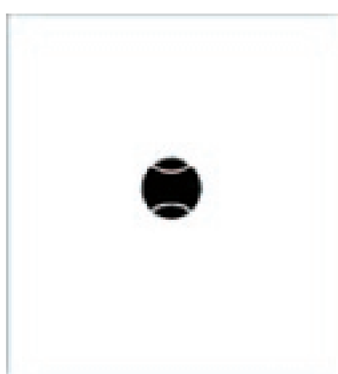
To the right is a graph that shows how pitch speed is affected by wind speed. The line on the graph shows the general relationship between wind speed and pitch speed. Points A, B, and C represent three of the same type of fast pitch all thrown at the same initial speed from a pitcher's fingertips, but under different wind conditions.

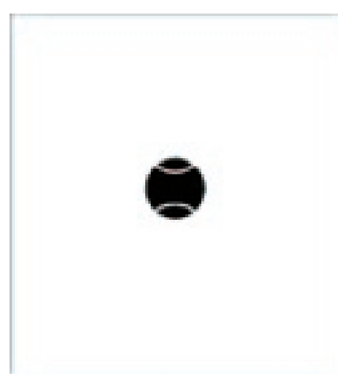


Data source: Kagan, D. (nd). The physics of pitching in the wind. Retrieved from: https://physics.csuchico.edu/baseball/Pubs/PitchingWindLong.pdf

Question 1) Draw three different free-body diagrams (A, B, and C), one for each point marked on the graph. In each free-body diagram, show all the contact forces on the ball after the ball has left the pitcher's hand. Draw arrows to show the relative strength of forces on the ball. Make sure to include the relative strength and direction of the forces on the ball due to its interaction with the air.







Question 2) Use your free-body diagrams on the previous page to help answer this question: If all three pitches (A, B, and C) had equal amounts of KE when they left the pitcher's hand, would they all have the same amount of KE when they reach home plate? Why or why not?

Question 3) How would you design an investigation using materials we have used in class to collect evidence for all 3 pitches to support or refute your claim for question 2? List the items and objects you will use in your investigation. Then describe the procedures for setting up and carrying out your investigation.

The items and objects I will use in my investigation:

Baseball items	Classroom items used to simulate baseball items
Bat	
Pitcher	
Ball	
Wind	

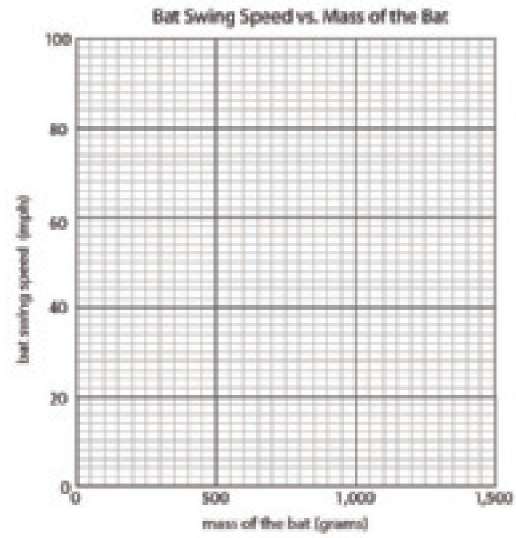
Other items needed to collect measurements and data:

My plan for setting up and carrying out my investigation:

Representing and Explaining the Relationships between Bat Speed and Bat Mass

The data table below shows how fast a major league power hitter can swing a bat with different amounts of mass. The mass of the bat was the independent variable in this investigation, and the speed of the bat swing was the dependent variable.

Mass of the bat (grams)	Bat swing speed (mph)
284	74
340	70
652	71
907	62
964	62
1191	61
1361	57



Question 4) Make a coordinate plot of the data from the table above.

Question 5) After graphing your data, draw a line of best fit for it.

Question 6) Use your line of best fit to predict how fast a player could swing a bat with a mass of 779 grams.

Record your prediction here: ______________________

Question 7) If a batter can apply the same amount of maximum force from their hands to each bat to swing it, why would the speed of the bat swing decrease as the mass of the bat increases? Explain this in terms of a chain of cause and effect using forces, energy transfer, and kinetic energy.

____

____

____

What has a bigger effect on kinetic energy of the bat and the ball—increasing the speed of the bat or increasing the mass of the bat?

Bat weight (g)	Speed of ball after contact (mph)
570	68.5
710	73.0
850	76.2
990	78.6
1,140	80.4

Bat swing speed (mph)	Speed of ball after contact (mph)
20.5	60.2
27.3	68.8
34.3	76.2
41.0	83.8
47.9	91.4

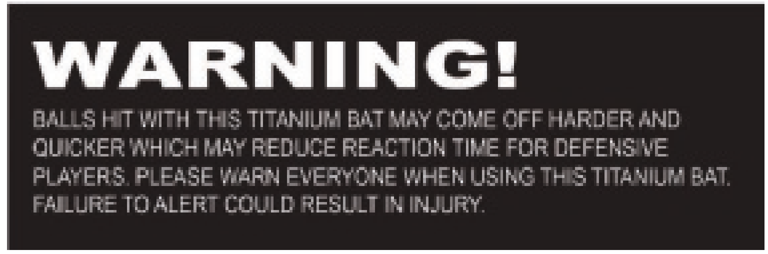
Question 8) Use the data from the tables above to determine which has a bigger effect on speed of the ball after it is hit, increases in the mass of a bat or increases in the swing speed of the bat. Show any calculations you do to determine which has a bigger effect.

Question 9) Some baseball stadiums (such as Coors Field in Denver, Colorado, which is the home stadium for the Colorado Rockies) are located at much higher altitude than most stadiums. Coors Field is 5,200 feet (almost a mile) above sea level. At this higher altitude there are fewer air particles in a given volume of air than at lower altitudes. Assume that the data shown in the two data tables in question 8 were collected at a stadium close to sea level (lower elevation). How would you expect the patterns in both tables to compare if you collected new data on bat weight vs. speed of ball after impact and bat swing speed vs. speed of ball after impact at Coors Field, where the air is less dense than air near sea level? Why?

Does the type of bat affect the amount of kinetic energy in the bat and ball?

Some people think it's important to have rules about the type of bats that players can use. For example, in major league baseball, players are only allowed to use wooden bats, while in NCAA baseball, bats made from metal and other composite materials are allowed. Titanium bats, however, are banned in most baseball clubs.

A coach argues that the reason for this is that the material the bat is made of causes it to **produce higher peak forces** in a collision than other bats because it **deforms less in a collision**.



Warning shown on the bat label

Question 10) Does the warning on the bat label shown above support both parts of the coach's argument about forces and deformation?

Question 11) Do you think that objects or materials that deform less in a collision spring back quicker or slower than objects that deform more? Why or why not?

Question 12) If you were playing baseball against another team and had all the data above for the other team and the conditions for that day, what single factor (wind speed and direction, elevation of the stadium, bat mass, bat swing speeds of players, bat material) would you consider the most when adjusting your game play? Why?

LESSON 10: ANSWER KEY 1

Key 1: Baseball Assessment

Scoring Guidance. The elements described below would be considered an exemplary response at this point in the unit. These are shown as purple text or in purple diagrams below the related question. In some cases different elements of the response are identified with a separate + symbol. These +'s are not meant to be all inclusive; they are suggestions for what you may see your students include.

If several of the ideas marked with a + are missing from a student's response, this may indicate the student has not mastered the science ideas or that the student may be struggling to bring those ideas together in a written explanation or model. Additional probing of their thinking can provide insight about whether the student is struggling with a science practice or science idea, or both. If all or almost all of the ideas marked with a + are present in a student's response, this may indicate the student has mastered the science ideas and is able to use them in a written explanation or explanatory model.

At each level of organized baseball, there are rules in place about what type of bat and ball can be used. These rules help ensure the game play remains competitive, fair, and fun. The type of bat and ball are the two major factors that game organizers can control. But there are a lot of other factors that people claim also have a big impact on game play that cannot be controlled, such as weather conditions, location of the stadium, and the strength of the players.

Answer the prompts below to figure out how these factors could impact the game of baseball.

Weather Conditions and Pitch Speed

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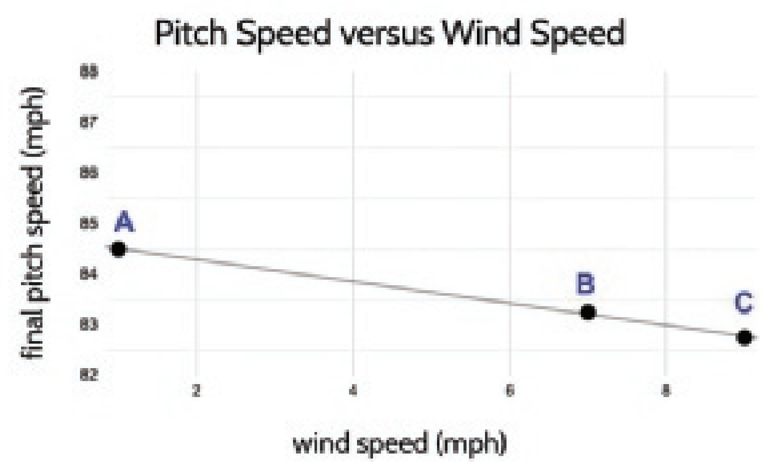
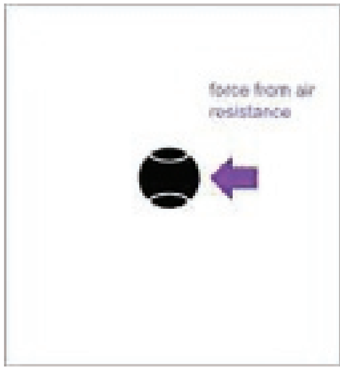


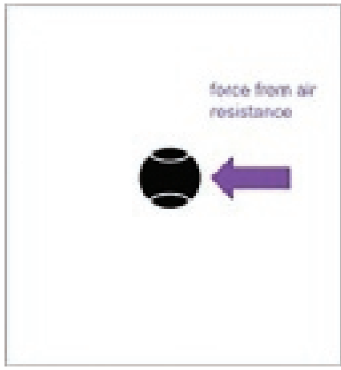
Data source Kagan, D. (nd). The physics of pitching in the wind. Retrieved from: https://physics.csuchico.edu/baseball/Pubs/PitchingWindLong.pdf

Question 1) Draw three different free-body diagrams (A, B, and C), one for each point marked on the graph. In each free-body diagram, show all the contact forces on the ball after the ball has left the pitcher's hand. Draw arrows to show the relative strength of forces on the ball. Make sure to include the relative strength and direction of the forces on the ball due to its interaction with the air.

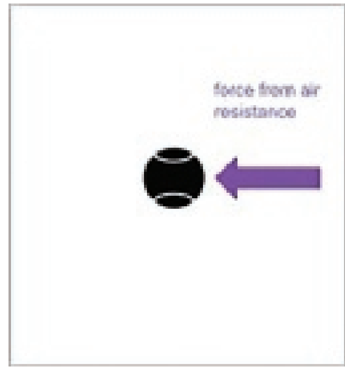
A



B



C



+ An arrow labeled as the force from air resistance should be on each ball.

+ The arrow should be facing to the left, with its tip touching the right side of the ball.

+ Alternatively, the images could be flipped with the arrow coming from the other direction as an alternate perspective, as long as all forces and strengths do not change in the representation.

+ The arrow length should get longer going from A to B and from B to C.

Question 2) Use your free-body diagrams on the previous page to help answer this question: If all three pitches (A, B, and C) had equal amounts of KE when they left the pitcher's hand, would they all have the same amount of KE when they reach home plate? Why or why not?

+ Pitch A would have the most KE because it is losing less energy than balls B and C to air resistance because the strength of the force from that is the smallest on ball A.

+ Pitch C would have the least KE because it encounters more air resistance than balls A and B because the strength of the force from that is the greatest on ball C.

Question 3) How would you design an investigation using materials we have used in class to collect evidence for all 3 pitches to support or refute your claim for question 2? List the items and objects you will use in your investigation. Then describe the procedures for setting up and carrying out your investigation.

The items and objects I will use in my investigation:

Baseball items	Classroom items used to simulate baseball items
Bat	Peak force detector OR a box OR a cracker
Pitcher	Spring-scale launcher
Ball	Cart with paper on it
Wind	Fan

Other items needed to collect measurements and data:

+ Peak force detector such as a push-pull spring scale OR a box to measure the total distance over which a push is applied OR a timer or radar gun or other device to collect data on the speed of the cart

My plan for setting up and carrying out my investigation:

Example:

+ I would have three different cart setups: 1 cart with a fan in front, 1 cart with a fan behind it, and 1 cart with no fan.

+ I would release each cart with the same amount of kinetic energy from the spring scale.

+ At the end of the track there would be a peak force detector placed in the same location for each cart.

+ I would measure the damage from the collision of the cart with the peak force detector at the end of the track for each condition.

Representing and Explaining the Relationships between Bat Speed and Bat Mass

The data table below shows how fast a major league power hitter can swing a bat with different amounts of mass. The mass of the bat was the independent variable in this investigation, and the speed of the bat swing was the dependent variable.

Mass of the bat (grams)	Bat swing speed (mph)
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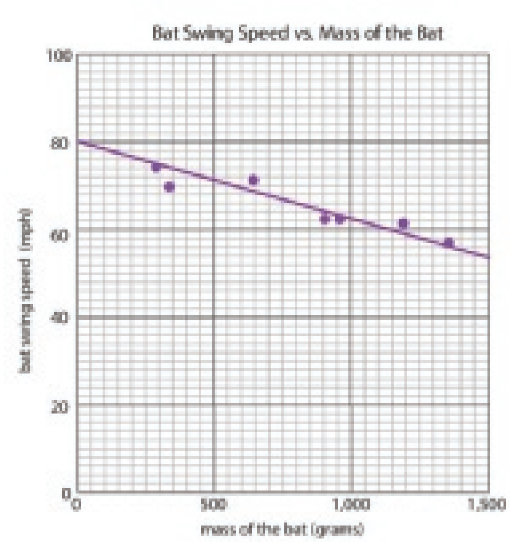

Question 4) Make a coordinate plot of the data from the table above.

Question 5) After graphing your data, draw a line of best fit for it.

+ See graphed answer above.

Question 6) Use your line of best fit to predict how fast a player could swing a bat with a mass of 779 grams. Record your prediction here:

+ The speed would be ~66 mph.

Question 7) If a batter can apply the same amount of maximum force from their hands to each bat to swing it, why would the speed of the bat swing decrease as the mass of the bat increases? Explain this in terms of a chain of cause and effect using forces, energy transfer, and kinetic energy.

+ The same amount of force will change the speed of a more-massive object less.

+ The same amount of force transfers the same amount of energy to an object, and since mass and speed are both related to the amount of KE an object has, increasing the mass of the object would require that its speed decreases.

+ It takes more energy to get something moving at the same speed as something with less mass.

What has a bigger effect on kinetic energy of the bat and the ball—increasing the speed of the bat or increasing the mass of the bat?

Bat weight (g)	Speed of ball after contact (mph)
570	68.5
710	73.0
850	76.2
990	78.6
1,140	80.4

Bat swing speed (mph)	Speed of ball after contact (mph)
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Question 8) Use the data from the tables above to determine which has a bigger effect on speed of the ball after it is hit, increases in the mass of a bat or increases in the swing speed of the bat. Show any calculations you do to determine which has a bigger effect.

+ Increases in the speed of the swing have a bigger effect on the speed of the ball after it is hit.

Question 9) Some baseball stadiums (such as Coors Field in Denver, Colorado, which is the home stadium for the Colorado Rockies) are located at much higher altitude than most stadiums. Coors Field is 5,200 feet (almost a mile) above sea level. At this higher altitude there are fewer air particles in a given volume of air than at lower altitudes. Assume that the data shown in the two data tables in question 8 were collected at a stadium close to sea level (lower elevation). How would you expect the patterns in both tables to compare if you collected new data on bat weight vs. speed of ball after impact and bat swing speed vs. speed of ball after impact at Coors Field, where the air is less dense than air near sea level? Why?

Students may interpret this question from different viewpoints in which the ball could be in contact with air, which would have an effect on the speed of the ball. Any of the following viewpoints are acceptable if justified with explanations of peak force and/or energy increases to the system.

From a pitching perspective

+ The speed of the pitched ball would increase because there is less air resistance on the ball. This increases the KE of one object in the system, which increases the peak forces in a collision, which should increase the speed of the ball after contact for every value tested.

From a batting perspective

+ The speed of the bat would increase because there is less air resistance on the bat, which allows the player to swing it faster, increasing KE. During contact, the bat's KE increases the peak forces in a collision, which should increase the speed of the ball after contact for every value tested.

From a ball-movement perspective at the moment of contact

+ The ball won't have moved through any air in the direction it would travel immediately after the bat contacts it (away from the bat), so the speed of the ball immediately after it is hit shouldn't change for any of the values tested.

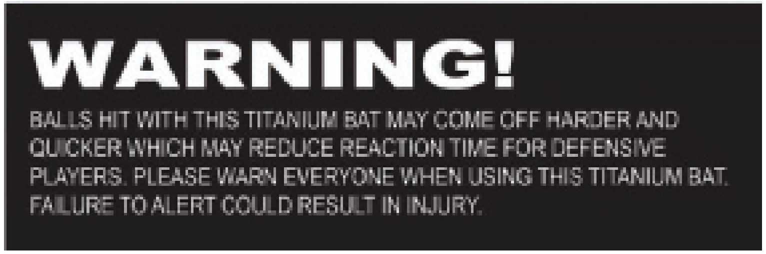
From a ball-movement perspective as it is traveling through the air after being hit

+ If ball speeds are measured after the ball has traveled through air a bit after being hit, the speed of the ball should be faster because there is less air resistance on the ball.

Does the type of bat affect the amount of kinetic energy in the bat and ball?

Some people think it's important to have rules about the type of bats that players can use. For example, in major league baseball, players are only allowed to use wooden bats, while in NCAA baseball, bats made from metal and other composite materials are allowed. Titanium bats, however, are banned in most baseball clubs.

A coach argues that the reason for this is that the material the bat is made of causes it to **produce higher peak forces** in a collision than other bats because it **deforms less in a collision.**



Warning shown on the bat label

Question 10) Does the warning on the bat label shown above support both parts of the coach's argument about forces and deformation?

+ It supports the argument about peak forces when it says "may come off harder and faster". Higher peak forces are related to higher amounts of kinetic energy for objects in a collision and will result in a higher speed of ball.

+ It does not support the argument that it is due to less deformation. We do not have enough data to make this claim. (If students try to make this claim by referencing ideas from Lesson 3, that is appropriate at this time. This idea will be explored further in Lessons 11–12.)

Question 11) Do you think that objects or materials that deform less in a collision spring back quicker or slower than objects that deform more? Why or why not?

+ Accept any response related to an amount of deformation and time to spring back. Some students may also connect this to peak forces and energy transfer. Any of these connections are appropriate at this time in the lesson set as they foreground relationships that they will explore in the last lessons of the unit.

Question 12) If you were playing baseball against another team and had all the data above for the other team and the conditions for that day, what single factor (wind speed and direction, elevation of the stadium, bat mass, bat swing speeds of players, bat material) would you consider the most when adjusting your game play? Why?

+ Accept all responses.

+ Rationale should reference any patterns and comparisons in the data showing a larger effect of one factor over another.

+ Note: The bigger purpose of this question is to provide a sense of closure on the framing of the entire question set that was introduced at the start of the assessment and to make the question set more relevant to students' individual experiences and perspectives.

Name: ______________________ Date: ______________

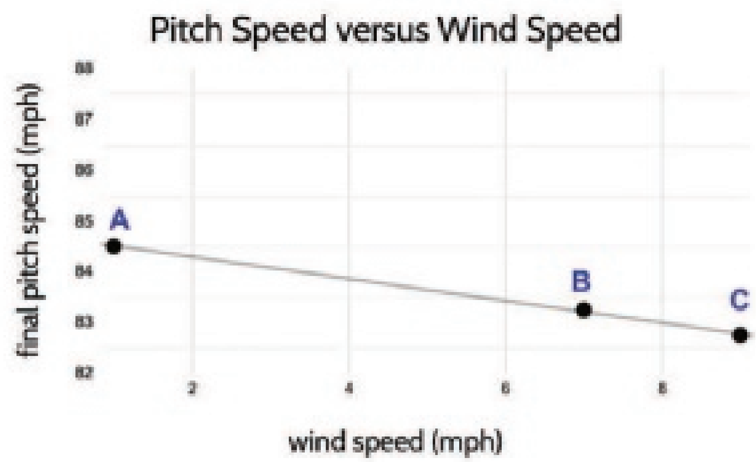
Baseball Assessment 2

At each level of organized baseball, there are rules in place about what type of bat and ball can be used. These rules help ensure the game play remains competitive, fair, and fun. The type of bat and ball are the two major factors that game organizers can control. But there are a lot of other factors that people claim also have a big impact on game play that cannot be controlled, such as weather conditions, location of the stadium, and the strength of the players.

Answer the prompts below to figure out how these factors could impact the game of baseball.

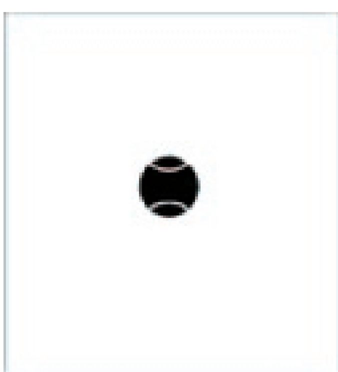
Weather Conditions and Pitch Speed

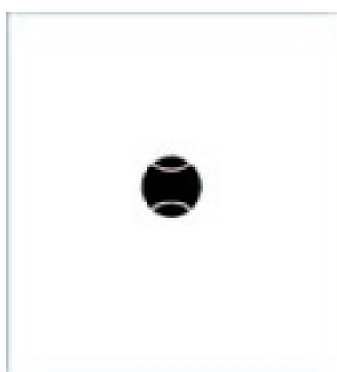
To the right is a graph that shows how pitch speed is affected by wind speed. The line on the graph shows the general relationship between wind speed and pitch speed. Points A, B, and C represent three of the same type of fast pitch all thrown at the same initial speed from a pitcher's fingertips, but under different wind conditions.

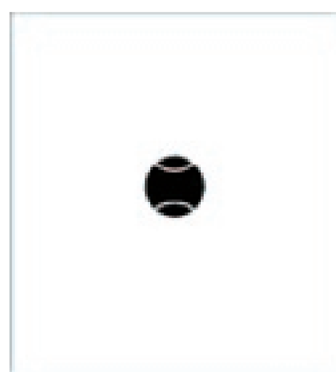


Data source: Kagan, D. (nd). The physics of pitching in the wind. Retrieved from: https://physics.csuchico.edu/baseball/Pubs/PitchingWindLong.pdf

Question 1) Draw three different free-body diagrams (A, B, and C), one for each point marked on the graph. In each free-body diagram, show all the contact forces on the ball after the ball has left the pitcher's hand. Draw arrows to show the relative strength of forces on the ball. Make sure to include the relative strength and direction of the forces on the ball due to its interaction with the air.







Question 2) Use your free-body diagrams on the previous page to help answer this question: If all three pitches (A, B, and C) had equal amounts of KE when they left the pitcher's hand, would they all have the same amount of KE when they reach home plate? Why or why not?

Question 3) How would you design an investigation using materials we have used in class to collect evidence for all 3 pitches to support or refute your claim for question 2? List the items and objects you will use in your investigation. Then describe the procedures for setting up and carrying out your investigation.

The items and objects I will use in my investigation and why I have chosen those items:

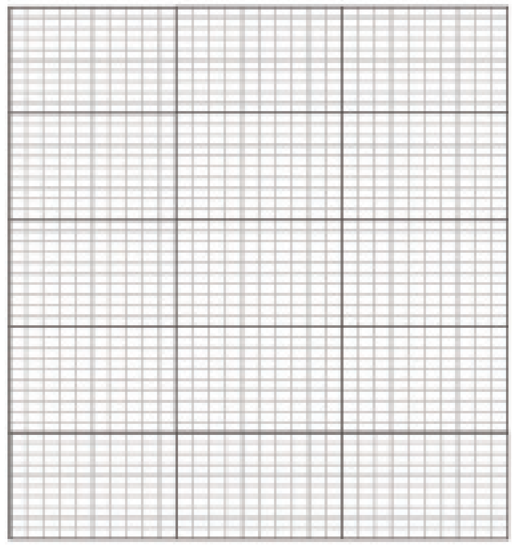
Other items needed to collect measurements and data:

My plan for setting up and carrying out my investigation:

Representing and Explaining the Relationships between Bat Speed and Bat Mass

The data table below shows how fast a major league power hitter can swing a bat with different amounts of mass. The mass of the bat was the independent variable in this investigation, and the speed of the bat swing was the dependent variable.

Mass of the bat (grams)	Bat swing speed (mph)
284	74
340	70
652	71
907	62
964	62
1191	61
1361	57



Question 4) Make a coordinate plot of the data from the table above.

Question 5) After graphing your data, draw a line of best fit for it.

Question 6) Use your line of best fit to predict how fast a player could swing a bat with a mass of 779 grams.

Record your prediction here: ______________________

Question 7) If a batter can apply the same amount of maximum force from their hands to each bat to swing it, why would the speed of the bat swing decrease as the mass of the bat increases? Explain this in terms of a chain of cause and effect using forces, energy transfer, and kinetic energy.

____

____

____

What has a bigger effect on kinetic energy of the bat and the ball—increasing the speed of the bat or increasing the mass of the bat?

Bat weight (g)	Speed of ball after contact (mph)
570	68.5
710	73.0
850	76.2
990	78.6
1,140	80.4

Bat swing speed (mph)	Speed of ball after contact (mph)
20.5	60.2
27.3	68.8
34.3	76.2
41.0	83.8
47.9	91.4

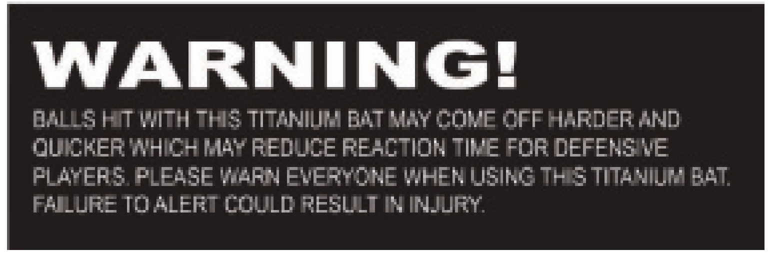
Question 8) Use the data from the tables above to determine which has a bigger effect on speed of the ball after it is hit, increases in the mass of a bat or increases in the swing speed of the bat. Show any calculations you do to determine which has a bigger effect.

Question 9) Some baseball stadiums (such as Coors Field in Denver, Colorado, which is the home stadium for the Colorado Rockies) are located at much higher altitude than most stadiums. Coors Field is 5,200 feet (almost a mile) above sea level. At this higher altitude there are fewer air particles in a given volume of air than at lower altitudes. Assume that the data shown in the two data tables in question 8 were collected at a stadium close to sea level (lower elevation). How would you expect the patterns in both tables to compare if you collected new data on bat weight vs. speed of ball after impact and bat swing speed vs. speed of ball after impact at Coors Field, where the air is less dense than air near sea level? Why?

Does the type of bat affect the amount of kinetic energy in the bat and ball?

Some people think it's important to have rules about the type of bats that players can use. For example, in major league baseball, players are only allowed to use wooden bats, while in NCAA baseball, bats made from metal and other composite materials are allowed. Titanium bats, however, are banned in most baseball clubs.

A coach argues that the reason for this is that the material the bat is made of causes it to **produce higher peak forces** in a collision than other bats because it **deforms less in a collision**.



Warning shown on the bat label

Question 10) Does the warning on the bat label shown above support both parts of the coach's argument about forces and deformation?

Question 11) Do you think that objects or materials that deform less in a collision spring back quicker or slower than objects that deform more? Why or why not?

Question 12) If you were playing baseball against another team and had all the data above for the other team and the conditions for that day, what single factor (wind speed and direction, elevation of the stadium, bat mass, bat swing speeds of players, bat material) would you consider the most when adjusting your game play? Why?

Name: ______________________ Date: ______________

LESSON 10: ANSWER KEY 2

Key 2: Baseball Assessment

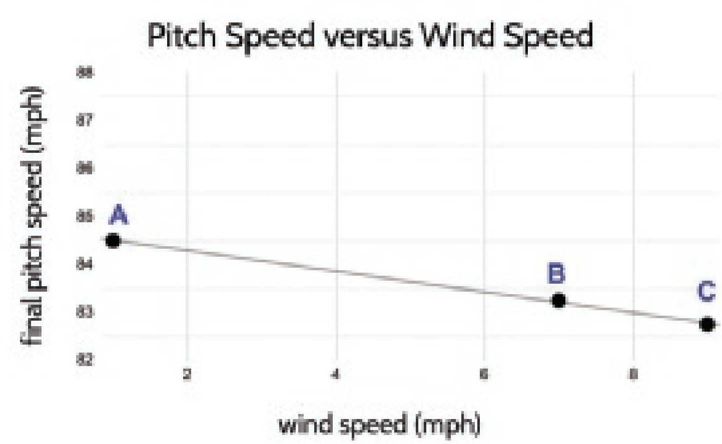
Scoring Guidance. The elements described below would be considered an exemplary response at this point in the unit. These are shown as purple text or in purple diagrams below the related question. In some cases different elements of the response are identified with a separate "+" symbol. These +'s are not meant to be all inclusive; they are suggestions for what you may see your students include.

At each level of organized baseball, there are rules in place about what type of bat and ball can be used. These rules help ensure the game play remains competitive, fair, and fun. The type of bat and ball are the two major factors that game organizers can control. But there are a lot of other factors that people claim also have a big impact on game play that cannot be controlled, such as weather conditions, location of the stadium, and the strength of the players.

Answer the prompts below to figure out how these factors could impact the game of baseball.

Weather Conditions and Pitch Speed

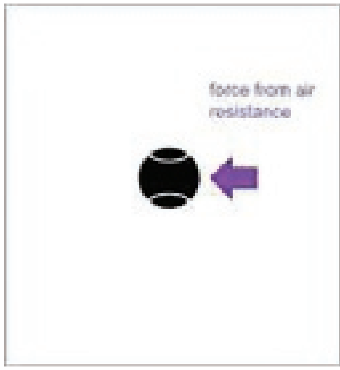
To the right is a graph that shows how pitch speed is affected by wind speed. The line on the graph shows the general relationship between wind speed and pitch speed. Points A, B, and C represent three of the same type of fast pitch all thrown at the same initial speed from a pitcher's fingertips, but under different wind conditions.



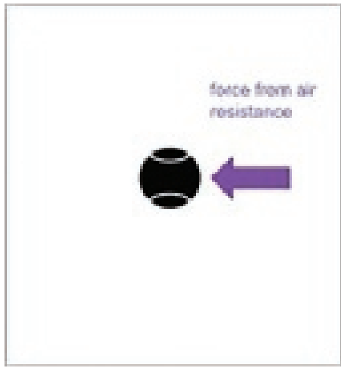
Data source: Kagan, D. (nd). The physics of pitching in the wind. Retrieved from: https://physics.csuchico.edu/baseball/Pubs/PitchingWindLong.pdf

Question 1) Draw three different free body diagrams (A, B, and C), one for each point marked on the graph. In each free-body diagram, show all the contact forces on the ball after the ball has left the pitcher's hand. Draw arrows to show the relative strength of forces on the ball. Make sure to include the relative strength and direction of the forces on the ball due to its interaction with the air.

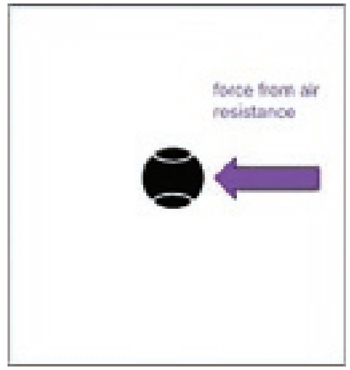
A



B



C



+ An arrow labeled as the force from air resistance should be on each ball.

+ The arrow should be facing to the left, with its tip touching the right side of the ball.

+ Alternatively, the images could be flipped with the arrow coming from the other direction as an alternate perspective, as long as all forces and strengths do not change in the representation.

+ The arrow length should get longer going from A to B and from B to C.

Question 2) Use your free-body diagrams on the previous page to help answer this question: If all three pitches (A, B, and C) had equal amounts of KE when they left the pitcher's hand, would they all have the same amount of KE when they reach home plate? Why or why not?

+ Pitch A would have the most KE because it is losing less energy than balls B and C to air resistance because the strength of the force from that is the smallest on ball A.

+ Pitch C would have the least KE because it encounters more air resistance than balls A and B because the strength of the force from that is the greatest on ball C.

Question 3) How would you design an investigation using materials we have used in class to collect evidence for all 3 pitches to support or refute your claim for question 2? List the items and objects you will use in your investigation. Then describe the procedures for setting up and carrying out your investigation.

The items and objects I will use in my investigation and why I have chosen those items:

+ Peak force detector/box/cracker
    + To detect the force of the collision
    + To simulate the bat
+ Spring scale launcher
    + To simulate the pitcher
    + To apply a force to the object that will be in motion/ball
+ Cart with paper on it
    + To simulate the ball
    + Paper to allow for air resistance to have an effect on the ball
+ Fan
    + To simulate wind
    + Applies a force to the paper/cart
+ Peak force detector such as a box or push pull spring-scale OR a box to measure the total distance a push is applied over OR a timer or radar gun or other device to collect data on the speed of the ball on the cart.

Other items needed to collect measurements and data:

+ Peak force detector such as a push-pull spring scale OR a box to measure the total distance over which a push is applied OR a timer or radar gun or other device to collect data on the speed of the cart

My plan for setting up and carrying out my investigation:

Example:

+ I would have three different cart setups: 1 cart with a fan in front, 1 cart with a fan behind it, and 1 cart with no fan.
+ I would release each cart with the same amount of kinetic energy from the spring scale.
+ At the end of the track there would be a peak force detector placed in the same location for each cart.
+ I would measure the damage from the collision of the cart with the peak force detector at the end of the track for each condition.

Representing and Explaining the Relationships between Bat Speed and Bat Mass

The data table below shows how fast a major league power hitter can swing a bat with different amounts of mass. The mass of the bat was the independent variable in this investigation, and the speed of the bat swing was the dependent variable.

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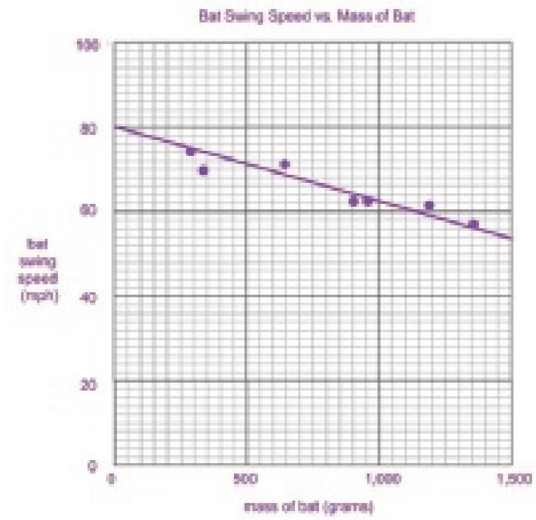

Question 4) Make a coordinate plot of the data from the table above.

Question 5) After graphing your data, draw a line of best fit for it.

+ See graphed answer above.

Question 6) Use your line of best fit to predict how fast a player could swing a bat with a mass of 779 grams. Record your prediction here:

+ The speed would be ~66 mph.

Question 7) If a batter can apply the same amount of maximum force from their hands to each bat to swing it, why would the speed of the bat swing decrease as the mass of the bat increases? Explain this in terms of a chain of cause and effect using forces, energy transfer, and kinetic energy.

+ The same amount of force will change the speed of a more-massive object less.

+ The same amount of force transfers the same amount of energy to an object, and since mass and speed are both related to the amount of KE an object has, increasing the mass of the object would require that its speed decreases.

+ It takes more energy to get something moving at the same speed as something with less mass.

What has a bigger effect on kinetic energy of the bat and the ball—increasing the speed of the bat or increasing the mass of the bat?

Bat weight (g)	Speed of ball after contact (mph)
570	68.5
710	73.0
850	76.2
990	78.6
1,140	80.4

Bat swing speed (mph)	Speed of ball after contact (mph)
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Question 8) Use the data from the tables above to determine which has a bigger effect on speed of the ball after it is hit, increases in the mass of a bat or increases in the swing speed of the bat. Show any calculations you do to determine which has a bigger effect.

+ Increases in the speed of the swing have a bigger effect on the speed of the ball after it is hit.

Question 9) Some baseball stadiums (such as Coors Field in Denver, Colorado, which is the home stadium for the Colorado Rockies) are located at much higher altitude than most stadiums. Coors Field is 5,200 feet (almost a mile) above sea level. At this higher altitude there are fewer air particles in a given volume of air than at lower altitudes. Assume that the data shown in the two data tables in question 8 were collected at a stadium close to sea level (lower elevation). How would you expect the patterns in both tables to compare if you collected new data on bat weight vs. speed of ball after impact and bat swing speed vs. speed of ball after impact at Coors Field, where the air is less dense than air near sea level? Why?

Students may interpret this question from different viewpoints in which the ball could be in contact with air, which would have an effect on the speed of the ball. Any of the following viewpoints are acceptable if justified with explanations of peak force and/or energy increases to the system.

From a pitching perspective
+ The speed of the pitched ball would increase because there is less air resistance on the ball. This increases the KE of one object in the system, which increases the peak forces in a collision, which should increase the speed of the ball after contact for every value tested.

From a batting perspective
+ The speed of the bat would increase because there is less air resistance on the bat, which allows the player to swing it faster, increasing KE. During contact, the bat's KE increases the peak forces in a collision, which should increase the speed of the ball after contact for every value tested.

From a ball-movement perspective at the moment of contact
+ The ball won't have moved through any air in the direction it would travel immediately after the bat contacts it (away from the bat), so the speed of the ball immediately after it is hit shouldn't change for any of the values tested.

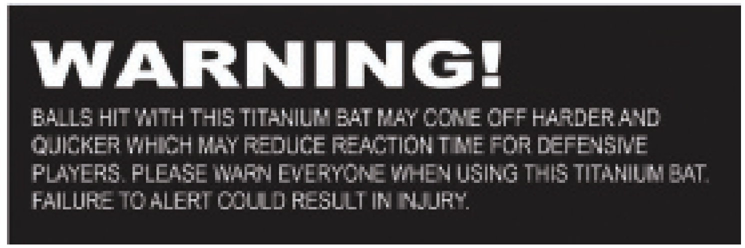
From a ball-movement perspective as it is traveling through the air after being hit

+ If ball speeds are measured after the ball has traveled through air a bit after being hit, the speed of the ball should be faster because there is less air resistance on the ball.

Does the type of bat affect the amount of kinetic energy in the bat and ball?

Some people think it's important to have rules about the type of bats that players can use. For example, in major league baseball, players are only allowed to use wooden bats, while in NCAA baseball, bats made from metal and other composite materials are allowed. Titanium bats, however, are banned in most baseball clubs.

A coach argues that the reason for this is that the material the bat is made of causes it to **produce higher peak forces** in a collision than other bats because it **deforms less in a collision.**



Warning shown on the bat label

Question 10) Does the warning on the bat label shown above support both parts of the coach's argument about forces and deformation?

+ It supports the argument about peak forces when it says "may come off harder and faster". Higher peak forces are related to higher amounts of kinetic energy for objects in a collision and will result in a higher speed of ball.

+ It does not support the argument that it is due to less deformation. We do not have enough data to make this claim. (If students try to make this claim by referencing ideas from Lesson 3, that is appropriate at this time. This idea will be explored further in Lessons 11–12.)

Question 11) Do you think that objects or materials that deform less in a collision spring back quicker or slower than objects that deform more? Why or why not?

+ Accept any response related to an amount of deformation and time to spring back. Some students may also connect this to peak forces and energy transfer. Any of these connections are appropriate at this time in the lesson set as they foreground relationships that they will explore in the last lessons of the unit.

Question 12) If you were playing baseball against another team and had all the data above for the other team and the conditions for that day, what single factor (wind speed and direction, elevation of the stadium, bat mass, bat swing speeds of players, bat material) would you consider the most when adjusting your game play? Why?

+ Accept all responses.

+ Rationale should reference any patterns and comparisons in the data showing a larger effect of one factor over another.

+ Note: The bigger purpose of this question is to provide a sense of closure on the framing of the entire question set that was introduced at the start of the assessment and to make the question set more relevant to students' individual experiences and perspectives.

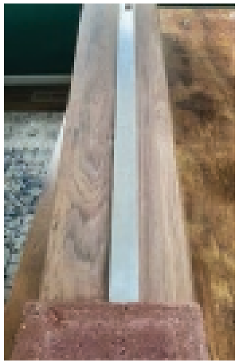
Setup for Collision Carts Demonstration

1. Add textbooks or binders to elevate one end of the flooring strip 8″-12″ to create a ramp.

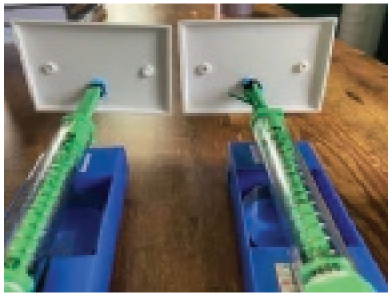
2. Angle the lower end of the vinyl flooring strip into the brick.

3. Place the metal track on the vinyl flooring strip and with its lower end against the brick.

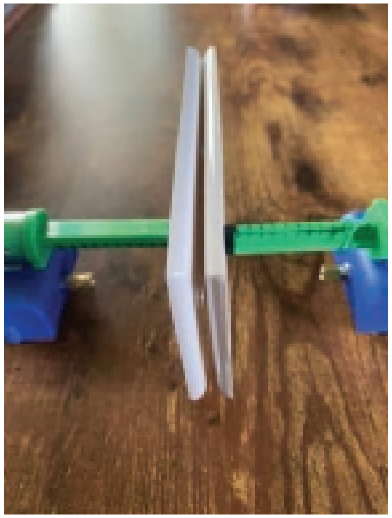
4. Place the push-pull spring scales on the carts using the hook and loop fasteners.



5. Mount a plastic, blank electrical plate on the end of the rod on each of the 2 push-pull spring scales using sticky tack.



6. Make sure that the two electrical plates touch flush when the carts are pushed together.



7. Using duct tape, tape down one cart at the bottom of the ramp about 4 inches away from the brick with its plate facing up the ramp.

LESSON 12: TEACHER REFERENCE 2

Material Charts

Material	Predicted performance
cotton balls	
balsa wood	
foam earplugs	
Styrofoam	
cardboard	
metal	
CD case plastic	
large bubble wrap	
small bubble wrap	
fabric	

Material	Predicted performance
cotton balls	
balsa wood	
foam earplugs	
Styrofoam	
cardboard	
metal	
CD case plastic	
large bubble wrap	
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fabric	

Material	Predicted performance
cotton balls	
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foam earplugs	
Styrofoam	
cardboard	
metal	
CD case plastic	
large bubble wrap	
small bubble wrap	
fabric	

Item Alignment Guide

Alignment between Lesson 15 assessment questions and related SEPs, DCIs, and CCCs	Part 1 Questions						Part 2 Questions				
	1a	1b	2a	2b	3a	3b	1	2	3	4	5
SEPs											
6.6, Constructing Explanations ~~or Designing a solution~~					X	X					
6.8 ~~Constructing Explanations or~~ Designing a solution							X	X	X	X	X
2.5 Developing and Using Models		X	X	X							
Subideas of targeted DCIs and related key model ideas											
All protection devices have some similar criteria and constraints; constraints vary based on a particular purpose or use case.							X	X			
Device shape, material, and structure have something to do with protective devices reducing damage to an object.	X	X							X	X	
Materials that reduce the peak forces in a collision reduce the forces equally on both objects that make contact during a collision.						X			X	X	
Materials that reduce peak forces have similar structures, such as air pockets or space for air and the ability to deform when a contact force is applied.	X	X								X	
More time in contact leads to a reduction in peak forces in a collision.										X	
The more area forces are distributed over, the smaller the amount of peak force per unit area.										X	
The net force of objects whose motion isn't changing is 0 (e.g., a cushioner being compressed between two other objects).				X							
When two objects are in contact with each other, forces are exerted on both objects in opposite directions; the strength of the force on one object is equal to the strength of the force on the other object.				X							
All criteria cannot be perfectly met all the time for all designs; most design solutions take into consideration trade-offs.											X
Considerations can be ranked or prioritized to help make design changes or decisions.								X			
An important criterion to consider is what the user or consumer of a solution wants.								X			
Redesign is informed by evaluating possible trade-offs.											X
CCCs											
6.1, 6.2 Structure and function	X	X				X	X			X	
7.1, 7.2 Stability and change				X		X					X
2.2 Cause and effect						X		X			X
4.1,4.2 Systems and system models			X	X					X		

Name: ____________________ Date: ____________________

Part 1: Cheerleading Headgear Assessment

Protecting Athletes' Heads and Brains While Cheerleading

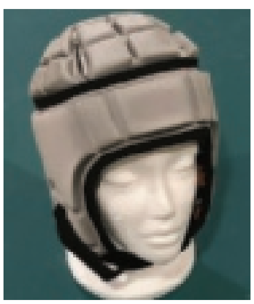
Many sports require or recommend helmets for protecting athletes' heads and brains. There are helmets for biking and skateboarding, helmets for baseball and football, helmets for rock climbing, and some people are even recommending headgear for soccer players. All of these are intended to prevent damage to the head or brain in the event of a collision.

There are sports people participate in like basketball, soccer, and cheerleading where helmets or headgear are not required even though concussions and other head injuries happen often. In cheerleading, concussions are very common. At least ⅓ of all injuries in cheerleading are concussions, usually from falling or head contact with the floor. In one recent year of college sports, the cheerleaders at the University of Georgia had a higher rate of concussions than the football or soccer players. How could cheerleaders protect their heads during competition?

Watch the video with your class to see the kinds of movements that the cheerleading athletes experience.

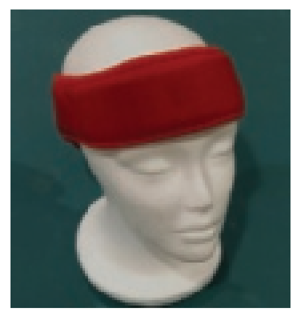
Part 1: Evaluating headgear

Here are three different headgear devices that are currently being marketed as protection from potential concussions in cheerleading.



Design #1

Design #2



Design #3

The headgear devices shown above were initially designed for other sports, and then people started using them for cheerleading.

1a. If you were a protective headgear device designer evaluating the materials being used in another company's design, what properties or materials would you expect to see in a good protective device if it were cut open?

1b. Draw a model of the material structure you would expect to see in the design described in 1a. In your model, label each design feature. For each design feature you label, explain in words how the structural properties help it function as a protective material.

2a. When any of the three designs shown above are worn on a person's head, the person's head is in contact with the headgear. When a person falls to the floor and hits their head, the headgear makes contact with the ground.

Draw and label a diagram that shows all three of these objects (head, headgear, ground) in contact with each other at the point in time when the collision with the ground first starts.

2b. Draw three free body diagrams, one for each object in your system in 2a. Include the following details in each diagram:

- Show the strength of the forces applied to each object in the system.
- Label what is applying this force to that object.
- Show the direction of these forces.
- Label the surface they are applied to.

3a. During practice, a flyer (a person launched into the air) does not want to wear their headgear. Another member of the squad, a base (a person who launches the flyer and stays on the ground), asks the flyer to wear their headgear because it will not only protect the flyer, but it will also further protect the base if their heads collide. Do you agree or disagree with this claim?

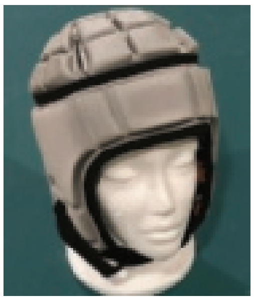
3b. Support or refute this claim by citing evidence from investigations we did and using any related science ideas we developed to defend your argument.

Name: ______________________ Date: ______________________

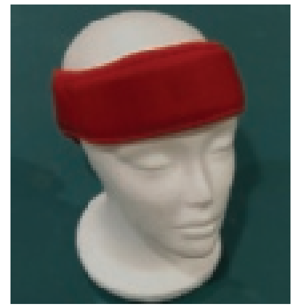
Part 2: Cheerleading Headgear Assessment

Part 2: Designing an Optimal Solution

Here are three different headgear devices used for cheerleading that you reviewed in part 1 of this assessment.


Design #1


Design #2


Design #3

These headgear devices were initially designed for other sports and then later people started using them for cheerleading. In competitions, cheerleading teams can earn points for more-advanced stunts and showmanship. The higher and more complex the throws and gymnastics, the more potential points can be earned by a team. Teams are also given points for engaging the crowd and overall appearance of the team.

Your task is to create an optimal headgear design for a cheerleader to wear in a competition. Complete the prompts on the next page to describe your design choices.

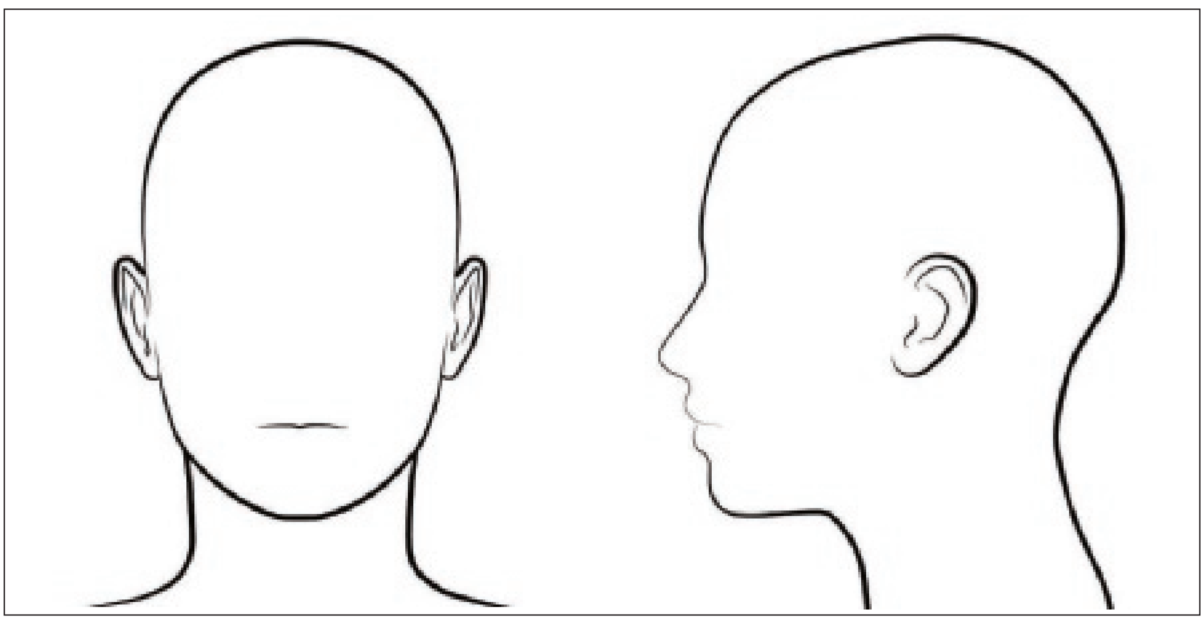
Considerations for design

1. What is the purpose of the design? What criteria does the headgear you design need to meet?

2. Pick one stakeholder who will be affected by your design and design with that person in mind.
   - Who is the stakeholder you are designing for?
   - What constraints do you anticipate your stakeholder will bring to your design? List at least 3 constraints that you think a helmet designer would have to consider.

Your design

3. Use words and pictures to show the structure of your design solution. In your design solution, make sure to label the different parts and materials used in the structure. Draw the proposed design on, over, and around the 2 views of the head shown below.



4. Explain how the materials in your design in #3 will function to reduce peak forces on a team member's brain in a collision. Describe how any smaller-scale structures (small and microscopic) that make up your materials help contribute to their function.

5. Write an argument for why your design solution is optimal and meets the needs of your stakeholder. If you made trade-offs, discuss what trade-offs you made and why. [As an alternative to writing your argument, you can use this space to prepare to *present* your explanation orally instead. Think about any imagery (diagrams, pictures, drawings) you want to include in your presentation and how you will convey all the components of your design solution (why it is optimal and meets the stakeholder needs). If you choose this route, make a plan with your teacher for when you can present your explanation.]

Name: ______________________ Date: ______________

LESSON 15: ANSWER KEY

Part 1 Key: Cheerleading Headgear Assessment

Scoring Guidance. The elements described below would be considered an exemplary response at this point in the unit. These are shown as purple text or in purple diagrams below the related question. In some cases different elements of the response are identified with a separate + symbol These +'s are not meant to be all inclusive; they are suggestions for what you may see your students include.

If several of the ideas marked with a + are missing from a student's response, this may indicate the student has not mastered the science ideas or that the student may be struggling to bring those ideas together in a written explanation or model. Additional probing of their thinking can provide insight about whether the student is struggling with a science practice or science idea, or both. If all or almost all of the ideas marked with a + are present in a student's response, this may indicate the student has mastered the science ideas and is able to use them in a written explanation or explanatory model.

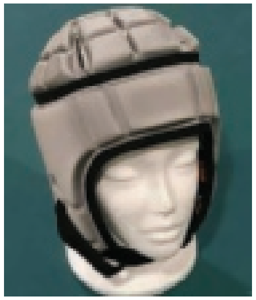
Protecting Athletes' Heads and Brains While Cheerleading

Many sports require or recommend helmets for protecting athlete' heads and brains. There are helmets for biking and skateboarding, helmets for baseball and football, helmets for rock climbing, and some people are even recommending headgear for soccer players. All of these are intended to prevent damage to the head or brain in the event of a collision.

There are sports people participate in like basketball, soccer, and cheerleading where helmets or headgear are not required even though concussions and other head injuries happen often. In cheerleading, concussions are very common. At least ⅓ of all injuries in cheerleading are concussions, usually from falling or head contact with the floor. In one recent year of college sports, the cheerleaders at the University of Georgia had a higher rate of concussions than the football or soccer players. How could cheerleaders protect their heads during competition?

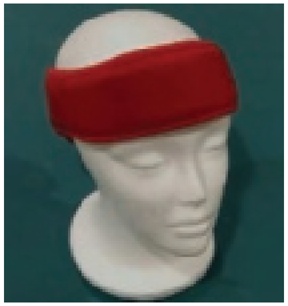
Watch the video with your class to see the kinds of movements that the cheerleading athletes experience.

Part 1 Here are three different headgear devices that are currently being marketed as protection from potential concussions in cheerleading.



Design #1

Design #2



Design #3

The headgear devices shown above were initially designed for other sports, and then people started using them for cheerleading.

1a. If you were a protective headgear device designer evaluating the materials being used in another company's design, what properties or materials would you expect to see in a good protective device if it were cut open?

+ The protective materials would have space for air.

+ The protective materials have the ability to deform a lot.

+ The protective materials might be thicker than other parts of the helmet.

+ The protective materials should be shaped so that the damaging object hits more protective material than other locations.

1b. Draw a model of the material structure you would expect to see in the design described in 1a. In your model, label each design feature. For each design feature you label, explain in words how the structural properties help it function as a protective material.

Students' models may vary in complexity or design but should include the following types of components (e.g., space for air). Their explanations for the structural properties should be aligned to the explanations provided here:

+ **Space for air.** This allows the material to have more space for material deformation.

+ **Ability to deform.** This allows the deformed material to apply contact forces over a longer time during the collision than if there was material in that space (this provides stronger contact forces than air resistance alone).

+ **Longer time where contact forces are applied.** This reduces the peak forces on the objects in the system.

+ Optional

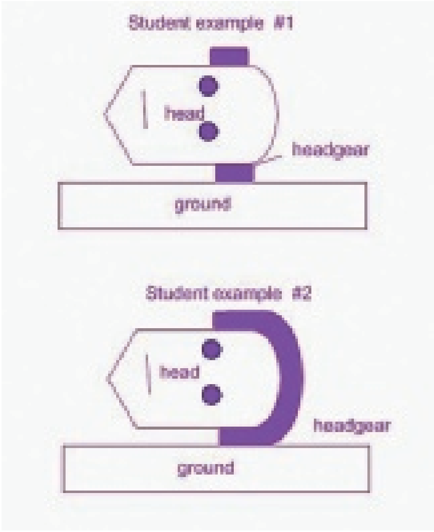
+ **Thickness of cushioning material.** The thicker the material is, while still being easily compressible, the more it will reduce the peak forces on the object that it is protecting.

+ **Shape.** Different shapes provide different thicknesses and contact points: the greater the area of contact, the more distributed or spread out the forces on the protected object.

2a. When any of the designs above are worn on a person's head, the person's head is in contact with the headgear. When a person falls to the floor and hits their head, the headgear makes contact with the ground.

Draw and label a diagram that shows all three of these objects (head, headgear, ground) in contact with each other at the point in time when the collision with the ground first starts.

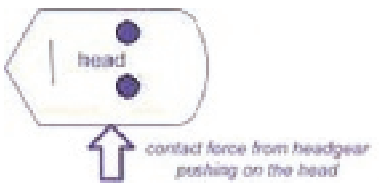
Two different example student models are shown to the right.



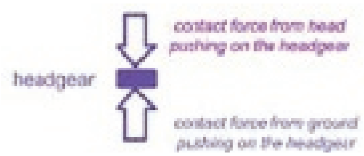
2b. Draw three free body diagrams, one for each object in your system in 2a. Include the following details in each diagram:

- Show the strength of the forces applied to each object in the system.
- Label what is applying this force to that object.
- Show the direction of these forces.
- Label the surface they are applied to.

Student example #1 in 2a is used to show one possible set of free-body diagrams below.



Free body diagram for the head



Free body diagram for the headgear

Free body diagram for ground

Key features to look for across all three free body diagrams

+ The size and length of the force arrows are the same in all diagrams.

+ There is a single force arrow on the head against the bottom side of it and pointing upward.

+ There is a single force arrow on the ground against the top side of it and pointing downward.

+ There are two force arrows on the headgear, one against the top side of it, pointing downward, and one against the bottom side of it, pointing upward.

3a. During practice, a flyer (a person launched into the air) does not want to wear their headgear. Another member of the squad, a base (a person who launches the flyer and stays on the ground), asks the flyer to wear their headgear because it will not only protect the flyer, but it will also further protect the base if their heads collide. Do you agree or disagree with this claim?

Students can agree or disagree with this claim as long as there is an opportunity for coherent argument for their position either way as outlined below.

3b. Support or refute this claim by citing evidence from investigations we did and using any related science ideas we developed to defend your argument.

All students should include the following evidence:

If students **agree (support the base person's claim)**: Students **must** argue that there is a contact force on the head from the headband as it is compressed and makes contact with the base person.

Evidence from investigations:

During the investigation of spring scales with cushioners in between

- Both spring scales showed the same amount of force when one spring scale pushed on another with a protective material in between.

During materials testing

- The cushioning materials reduced peak forces on both objects in a collision (with a constant amount of kinetic energy in the system before the collision).

In the spring scale distribution demonstrations and investigations:

+ The forces were equal on both sides of the protective materials (relevant for design #2 or design #3) *or*

+ Optional (if students are referring to design #1): In the case where there was a cushioning material shape with surface area that was different between one surface it was in contact with versus another, it may have further reduced the amount of force on one object by spreading that force over a larger area.

Science ideas

+ Forces are distributed equally between each object making contact in a collision.

  + Materials that reduce peak forces do so on both objects they are between in a collision.

  + The material can increase the time over which forces from the collision are applied to both people, which decreases the kinetic energy of the moving person (the flyer), which decreases the amount of peak force applied to each person in the system.

If students **disagree (refute the base person's claim):** Students must claim that the headband does not protect the entire head, so it is possible that the two heads would collide without the headband experiencing the contact force between both heads during the collision.

Evidence from investigations

+ During materials testing

  + Some materials that were better cushioners reduced peak forces more than others.

  + But with no protective material in the middle of the collision, the peak forces will be the same with no benefit to either person.

Science ideas

+ Objects in a collision experience forces only by contact interactions with other objects.

+ If the helmet is not in contact with the ground and the head during the collision, it cannot be compressed, and therefore cannot reduce the peak forces between the two objects.

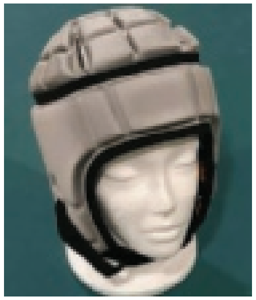
Part 2 Key: Cheerleading Headgear Assessment

Scoring Guidance. The elements described below would be considered an exemplary response at this point in the unit. These are shown as purple text or in purple diagrams below the related question. In some cases different elements of the response are identified with a separate + symbol These +'s are not meant to be all inclusive; they are suggestions for what you may see your students include.

If several of the ideas marked with a + are missing from a student's response, this may indicate the student has not mastered the science ideas or that the student may be struggling to bring those ideas together in a written explanation or model. Additional probing of their thinking can provide insight about whether the student is struggling with a science practice or science idea, or both. If all or almost all of the ideas marked with a + are present in a student's response, this may indicate the student has mastered the science ideas and is able to use them in a written explanation or explanatory model.

Part 2: Designing an Optimal Solution (20 min)

Here are three different headgear devices used for cheerleading that you reviewed in part 1 of this assessment.


Design #1


Design #2


Design #3

These headgear devices were initially designed for other sports and then later people started using them for cheerleading. In competitions, cheerleading teams can earn points for more-advanced stunts and showmanship. The higher and more complex the throws and gymnastics, the more potential points can be earned by a team. Teams are also given points for engaging the crowd and overall appearance of the team.

Your task is to create an optimal headgear design for a cheerleader to wear in a competition. Complete the prompts below to describe your design choices.

Considerations for design

1. What is the purpose of the design? What criteria does the headgear you design need to meet?

+ Purpose of the design is to provide protection to the head.

Criteria

+ Needs to have materials that have protective properties

  + ability to deform

  + space for air

  + thickness and shape optimized for the design solution

2. Pick one stakeholder who will be affected by your design and design with that person in mind.

- Who is the stakeholder you are designing for?
- What constraints do you anticipate your stakeholder will bring to your design? List at least 3 constraints that you think a helmet designer would have to consider.

Students should list a stakeholder who is relevant to the scenario. This stakeholder should be someone who either uses the design, benefits from the design, or is impacted by the design.

Potential constraints

  + size of helmet

  + amount of the head the helmet covers

  + thickness of helmet

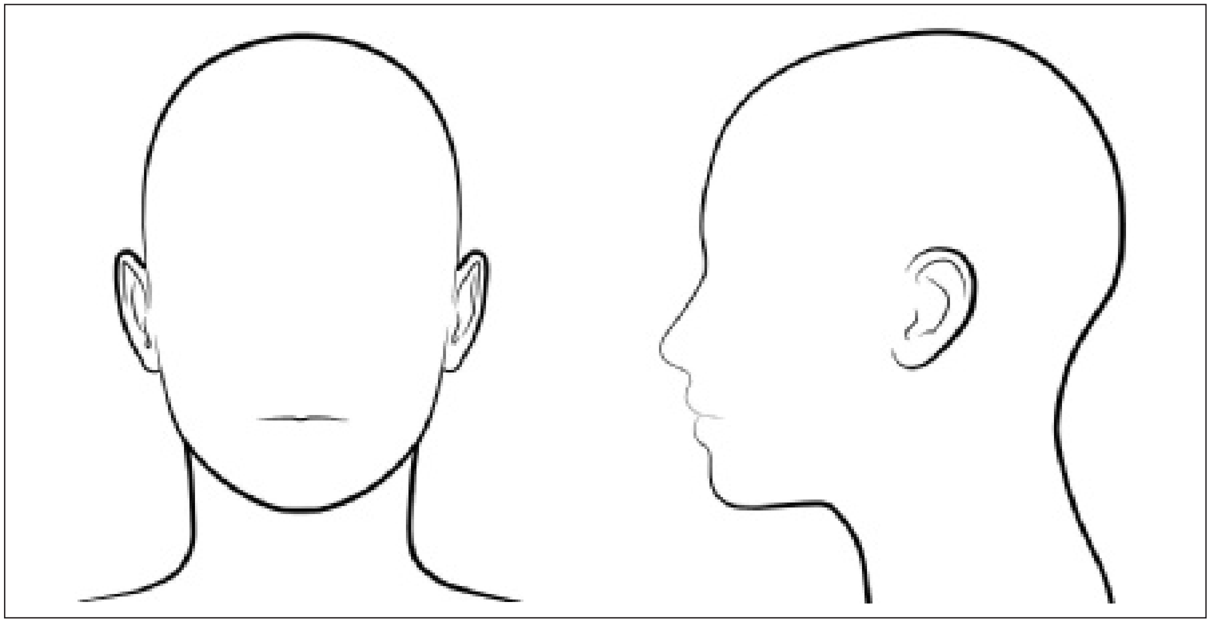
  + any aesthetic constraints

  + price

  + Students may list additional constraints. All applicable and reasonable constraints are acceptable.

Your design

3. Use words and pictures to show the structure of your design solution. In your design solution, make sure to label the different parts and materials used in the structure. Draw the proposed design on, over, and around the 2 views of the head shown below.



+ Students should draw their protective designs on the two outlines of heads.

+ Students should label the parts.

+ Students should show the different materials.

+ Students' drawings should show the coverage area of the protection device.

4. Explain how the materials in your design in #3 will function to reduce peak forces on a team member's brain in a collision. Describe how any smaller-scale structures (small and microscopic) that make up your materials help contribute to their function.

Student arguments should include how the materials will

+ have smaller pieces, layers, and sections of solid matter in them and have space for air to allow for the deformation of that solid matter.

+ deform over that space when a force is applied, leading to an increase in contact time and therefore a decrease in strength of forces.

+ optional: distribute the force over a greater surface area.

5. Write an argument for why your design solution is optimal and meets the needs of your stakeholder. If you made trade-offs, discuss what trade-offs you made and why. [As an alternative to writing your argument, you can use this space to prepare to *present* your explanation orally instead. Think about any imagery (diagrams, pictures, drawings) you want to include in your presentation and how you will convey all the components of your design solution (why it is optimal and meets the stakeholder needs). If you choose this route, make a plan with your teacher for when you can present your explanation.]

Optimal design solution argument

+ Look for students to make direct connections among the potential criteria constraints from question 2.

+ Students should show and/or explain how the trade-offs and stakeholder needs are addressed in the design.

Trade-offs

+ Look for students to point out specific constraints and compare the prioritization of the constraints.

+ Students should provide justification for the prioritization and evidence of the application of this trade-off in their designs.

Project Options Overview

While all students will be engaging in creating a presentation for investors, some students may benefit from an extension activity. Different types of extension activities for this project will fit the needs of different students and classrooms and provide different cognitive loads for students based on their abilities and interests. This document describes those optional opportunities for project extensions for students. Assign these optional activities as desired for students on an individual basis or as a class as time permits.

Optional activity 1: *Creating a Scale Model*

Creating a Scale Model focuses on the 7th grade geometry Common Core State Standards of building a device to scale. Some students may benefit from additional practice in this real-life application of this mathematical standard, or their design may be too large to create a standard prototype for presentation purposes.

Potential additional materials needed to engage in this activity include the following:

- materials for the creation of student designs
  - recyclable materials already identified for that purpose
  - discarded items to be repurposed

This handout is written so that students can go through the process of creating a scale model on their own. If students need help, walk through each step with them. It may help to revisit the Factors and Multiples Chart provided to discuss how multiples can be used to find the factors of different numbers and scale models can be determined by scaling up or down by the factors of the dimensions.

At the end of the handout, students will be prompted to visit with the teacher about their scale model before beginning to create their physical scale model prototype.

Optional activity 2: *Determining Your Prototype Testing Conditions*

Determining Your Prototype Testing Conditions focuses on developing a prototype to engage in the testing of the design. If wanted, students could engage in the iterative process of testing, redesigning, and retesting used in *Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)* and *Unit 7.2: How can we help people design a flameless heater? (Homemade Heater Unit)* and as referenced in the performance expectation MS-ETS1-4. The handout has students generate data to provide to investors about the performance of the design and provide evidence for the functionality of the proposed solution.

Potential additional materials needed to engage in this activity include the following:

- sugar glass of different thicknesses and sizes
- water balloons
- eggs in small plastic bags
- building materials

- access to a stairwell
- slingshot for larger objects (can be found for pumpkins online from various retailers)
- materials for the creation of student designs
  - recyclable materials already identified for that purpose
  - discarded items to be repurposed

In this handout, students will be asked to identify the proper testing conditions based upon the amount of kinetic energy that their proposed device will encounter in a collision. Students will be asked to diagram the testing procedure and create a data table to use for test results.

Students will be prompted to check in with their teacher before any building or testing of prototypes begins. If this handout is used, make sure to verify all decisions and testing conditions before allowing students to proceed with their plans.

Optional activity 3: *Optional Project Extensions*

Optional Project Extensions focuses on additional visual aid development for the purpose of the investor presentation. Students are directed to create an additional visual aid of their choice, including the options to create the following projects:

- poster
- brochure
- flyer
- infographic

Potential additional materials needed to engage in this activity include the following:

- paper and other presentation materials
- markers, colored pencils, rulers, and other writing materials
- technology resources
- For a full list of options related to technology use for the completion of this activity, see *Investor Presentation Choice and Platform Information.*

This project can be as big or as small as the student wants to create. Students will have the ability to pick their project platform and are prompted to share and discuss this choice with the teacher before beginning this extension activity.

LESSON 16: TEACHER REFERENCE 1

Investor Presentation Choice and Platform Information

Project Type Considerations

Below is a list of considerations for each type of project. Think about these options when allowing your students to select their project choice. Consider your materials available, space in your room, and other factors such as how students are expected to turn in their work. Remove any options from *Optional Project Extensions* if they do not fall in line with your school's privacy policies or student expectations. Student privacy policies vary widely by school and district. Remember to check with your school's student privacy policies before approving the use of any specific projects, websites, or apps.

Project type	Considerations
Posters, brochures, flyers	• This more-traditional option can be done without any digital tools. • Paper can easily be lost by students without a paper management system. • These items can be done on a variety of digital platforms as well. • Different digital tools have different sharing settings and capabilities.
Infographic	• Such a visual aid is more susceptible to copying and pasting. • It might require additional sources of data.
Prerecorded presentation	• Could be viewed before or after class • Easily shareable • Reduces anxiety for some students • Might require time to learn editing tools

Potential Digital Project Platforms

Below is an alphabetical list of some widely used digital project creation platforms along with their pros and cons. This list is not all-inclusive but will give an idea of different ways students can demonstrate their learning. Each platform is linked to the Commonsense.org review when available, if you would like further information regarding the digital tool.

Platform	Use	Pros	Cons
Adobe Spark	Adobe Suite has many different applications and uses. Can be used to create • posters • charts • flyers	• Very versatile • Many different presentation options • Looks professional • Web-based platform	• Meant for ages 13 and up, if no school login is available • Check sharing settings against school policies. • Choices could be overwhelming to some students. • Steeper learning curve than Google platforms
Google Docs	More-traditional word processing application Can be used to create • a script • brochures • flyers • charts	• Easy to use • Familiar to most students • Web-based platform • Different layouts exist on the Google suite for a variety of purposes. • Can be shared with select stakeholders	• Limited ability to reformat pages • Charts can be hard to lay out or organize in different ways. • Text direction cannot be changed.
Google Drawings	Online drawing tool similar to Microsoft paint application Can be used to create • posters • billboards • flyers	• Easy to use • Integrates with other Google applications • Can import images from search features • Can be shared with select stakeholders	• Has limited tools to utilize • No premade templates or layouts • Simplistic look vs. a more-sophisticated look achieved with Adobe tools

Platform	Use	Pros	Cons
Google Slides	Tool traditionally used to create presentations Can be used to create • posters • billboards • flyers	• Easy to use • Familiar to most students • Web-based platform • Multiple premade layouts and color schemes • Can be shared with select stakeholders	• Hard to create detailed drawings • Harder to export as a JPG if needed
iMovie	Tool traditionally used for creating and editing videos Can be used to create • recorded presentations	• Easy to use • Templates and layouts available • Allows for voice-overs • Would need a webcam or camera to create mock TikTok	• Available on iOS and macOS platforms • Limited video editing available
Keynote	Tool traditionally used to create presentations Can be used to create • posters • billboards • flyers	• Similar to Google Slides • Has more features than Google Slides • Basic graphics and layouts available • Voice-overs can be added but are more difficult to integrate.	• Available on iOS and macOS platforms • Harder to share with classmates and stakeholders
Microsoft PowerPoint	Tool traditionally used to create presentations Can be used to create • posters • billboards • flyers	• Similar to Google Slides • Has more features than Google Slides • Basic graphics and layouts available • Easy to record and play audio over slides	• Harder to share with classmates and stakeholders • School needs Microsoft Office license to utilize • Doesn't function as well on macOS devices

Platform	Use	Pros	Cons
Piktochart	Application typically used to create infographics Can be used to create • infographics • posters • flyers	• Students can create professional looking graphs and charts. • Templates available • Controlled sharing settings available	• Basic features are limited. • Does require a free login
Powtoon	Tool traditionally used to create presentations Can be used to create • posters • recorded presentations	• Many different presentation formats • Premade templates • Many different ways to share the product • A multitude of images and videos are available to use. • Easy to use • May need recording device if doing a newscast • Can upload and use your own videos • Web-based platform	• Students can add pictures and videos from a variety of sources, including Flickr, which may not be supported by some schools. • Check with student privacy policies if students use images or likenesses due to the shareability of Powtoon.
QuickTime	Traditional recording, video editing, and playback software included on Mac devices Can be used to create • recorded presentations	• Easy to use • Can upload or modify any videos • Can be used to record audio	• Microsoft version is no longer supported by Apple. • Comes with macOS • Does not have a lot of standard templates or music to utilize

Potential Accompanying Standards

Different projects will lend themselves to different potential standards for ELA, mathematics, and technology based upon their modality and presentation style. Use the tables below to help develop any accompanying rubrics or materials for students in your classroom. Consider sharing these standards with teammates who may also teach these content areas to develop a cross-curricular connection. The list below is not exhaustive and are only suggestions, not recommendations. Many states that do not use Common Core standards have similar areas such as reading, writing, speaking, and listening that can be cross-referenced. Ultimately, consult your own state adopted standards when deciding on any potential additional standard alignments.

ELA Common Core College and Career Readiness Standards Connections

Consider the following Common Core ELA standards for student use. Many standards are applicable to more than one project. Depending on state, this alignment may vary. Consult your state standards documents for further guidance.

Standard	Indicator	Statement
		Reading
Integration of Knowledge and Ideas	CCSS.ELA-LITERACY.CCRA.R.7	Integrate and evaluate content presented in diverse media and formats, including visually and quantitatively, as well as in words.
		Writing
Text Types and Purposes	CCSS.ELA-LITERACY.CCRA.W.2	Write informative/explanatory texts to examine and convey complex ideas and information clearly and accurately through the effective selection, organization, and analysis of content.
Production and Distribution of Writing	CCSS.ELA-LITERACY.CCRA.W.4	Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
Production and Distribution of Writing	CCSS.ELA-LITERACY.CCRA.W.6	Use technology, including the Internet, to produce and publish writing and to interact and collaborate with others.

		Speaking and Listening
Comprehension and Collaboration	CCSS.ELA-LITERACY.CCRA.SL.2	Integrate and evaluate information presented in diverse media and formats, including visually, quantitatively, and orally.
Presentation of Knowledge and Ideas	CCSS.ELA-LITERACY.CCRA.SL.4	Present information, findings, and supporting evidence such that listeners can follow the line of reasoning and the organization, development, and style are appropriate to task, purpose, and audience.
Presentation of Knowledge and Ideas	CCSS.ELA-LITERACY.CCRA.SL.5	Make strategic use of digital media and visual displays of data to express information and enhance understanding of presentations.

Common Core Mathematics Standard Connection

Consider the following Common Core math standard for student use if a scale model is created. The creation of a scale model requires the use of factors and multiples. While the concept of factors and multiples are developed in grade 4, these ideas are utilized in the creation of scale models in middle school. Depending on the state, this alignment may vary. Consult your state standards documents for further guidance.

Standard	Indicator	Statement
Grade 7 – Geometry	CCSS.MATH.CONTE NT.7.G.A.1	Solve problems involving scale drawings of geometric figures, including computing actual lengths and areas from a scale drawing and reproducing a scale drawing at a different scale.

ISTE Standard Connection

Consider the following technology standards for student use. Many ISTE standards are applicable to more than one project. Depending on the state, this alignment may vary. Consult your state standards documents for further guidance.

Standard	Indicator	Statement
Computational Thinker	5b	Students collect data or identify relevant data sets, use digital tools to analyze them, and represent data in various ways to facilitate problem-solving and decision-making.

Creative Communicator	6a	Students choose the appropriate platforms and tools for meeting the desired objectives of their creation or communication.
Creative Communicator	6c	Students communicate complex ideas clearly and effectively by creating or using a variety of digital objects such as visualizations, models or simulations.
Creative Communicator	6d	Students publish or present content that customizes the message and medium for their intended audiences.
Global Collaborator	7a	Students use digital tools to connect with learners from a variety of backgrounds and cultures, engaging with them in ways that broaden mutual understanding and learning.

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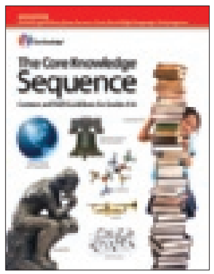

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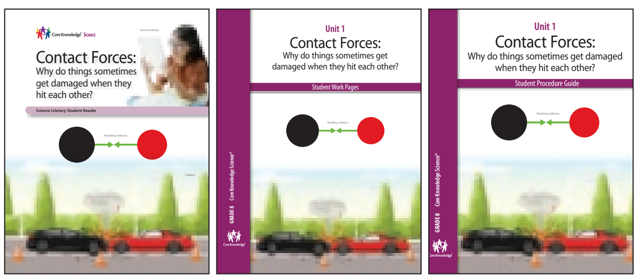

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